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Opinion

The Handicap of New Technologies: Nobody Wants to Be the First for Commercial Application

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Abstract: This work highlights the frustration that a researcher may face when trying to convince people in industries to use a new technology that has been developed in a small-scale laboratory. A moderate-reaction-severity process for hydrotreating of heavy crude oil (HIDRO-IMP technology) in fixed-bed reactors is used as an example. Although the development of such a technology has been scaled-up from bench and pilot-plant scales to a semi-commercial level with positive technical and economical results, the people in petroleum refinery who make decisions on the suitability of technologies for commercial implementation always ask for previous applications of the process developed. The different stages of development of the HIDRO-IMP technology are commented on, and some results that corroborate its feasibility for commercial application are discussed.

Keywords: technology development; semi-commercial level; commercial application; HIDRO-IMP

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1. Introduction

The main wish of a scientific researcher is to see the results of their laboratory investigation in commercial application. Most of the time, research is conducted to obtain more knowledge on certain phenomena without a clear objective for possible commercial application. This mostly happens in universities, although recently, these have been receiving funding from the industrial sector and are needing to focus more on providing solutions to industries. Achieving the goal of the commercial application of a technology can sometimes be frustrating, depending on various factors such as the following: (1) Competitors, which typically dominate the market with old, mature, and well-established technologies that are preferred by those in the industry—not exactly by being the best option but due to their long experience working with them. Even if the new technology proposed shows better economic benefits (lower investment and operating costs, with the consequent higher internal rate of return and payback period) and superior performance (higher yields and better-quality products), those in the industry still prefer the processes that are already in use. This preference may be influenced by other non-technical factors, which will not be commented on here. (2) Market needs: there is no global solution to all problems—one technology can be attractive for some clients but not for others. For instance, European refineries mostly use catalytic hydrocracking processes to produce low-sulfur diesel, whereas in refineries in America (the continent), catalytic hydrotreating process is preferred. Thus, it would be complicated to compete in one of these markets with technologies different from those that they use. (3) Investment costs: currently, some industries are facing problems related to investing in installing new technologies, and they choose to revamp the old processes available. Even if there is an investment group that proposes a service with a fee in return, with zero investment cost, they are sometimes not interested in such a business model.

If the technology is new, the most commonly asked question when trying to convince end users to install a plant in their facilities is, where has this technology been used before? It is fully understandable that the end user is concerned about the potential risks associated with the commercial application of new technologies. However, it is also true that successful technological developments need to be scaled up for commercial application.

In the case of the petroleum refining industry, and surely in other industries as well, some large companies have their own research centers, and, once a technology is developed, access to industrial application is relatively easy. Unfortunately, this is not the case for many universities and research institutions, which need to demonstrate that a developed technology is indeed better than commercially available ones and that it is economically attractive to be interested in it. In any case, decision-making people always ask for previous commercial applications of a new technology. Can you imagine the face of researchers when they are asked for this? The common answer of a technology developer is, how can I have my technology commercialized if there is no chance to demonstrate it at the industrial level? This seems to be the same controversy as when a recently graduated engineer looks for a job, with employers asking for previous experience from young engineers who have never worked.

Even if a semi-commercial demonstration test of a technology has been performed, sometimes, this is not enough to obtain the authorization for its industrial implementation, which is worst if the testing level is only at the laboratory scale. In summary, nobody wants to be the first for the commercial application of new technologies. This situation motivated me to share my own experience of technology development with the scientific community, as well as my frustration for not achieving my scientific wish—at least, so far.

2. The HIDRO-IMP Technology

The technology that I am referring to is HIDRO-IMP. The word "HIDRO" refers to hydrogen in Spanish (hidrógeno). It is a fixed-bed catalytic process for the hydrotreating of heavy and extra-heavy crude oils and residua that works at moderate reaction severity (under mild conditions of temperature and pressure). The HIDRO-IMP technology was developed by the Mexican Institute of Petroleum (IMP). Figure 1 shows a simplified flow process diagram of the HIDRO-IMP technology. As can be observed, the plant configuration is a typical one, found in other hydrotreating processes. That is, it includes feed conditioning, fixed-bed reactors, separation products, and hydrogen recycling as main sections. The equipment involved in each section is the same as in other commercial hydrotreating plants, e.g., fixed-bed reactors, pumps, heaters, compressors, and separators; mainly, there is no complex equipment, and there is therefore no need for a big plant to demonstrate the performance of this technology.

The initial step involves splitting full boiling-range heavy crude oil into a light fraction and a heavy fraction (typically, a sort of atmospheric residue). The heavy fraction is subjected to hydrotreating conditions in a first fixed-bed reactor, where substantial metal and asphaltene removal is achieved and at least a portion of sulfur and nitrogen is eliminated. The partially converted products from this stage enter a second fixed-bed reactor to achieve substantial removal of sulfur and nitrogen and a moderate level of hydrocracking. The reactor effluent is sent to a high-pressure separator where the liquid products are recovered from the gases. The liquid stream from the high-pressure separator is provided with additional stripping to remove the remaining dissolved hydrogen sulfide. The gas mixture from the high-pressure separator is fed to the scrubbing unit to remove hydrogen sulfide and ammonia, and the resulting high hydrogen purity stream is recompressed and recycled to the reaction system. Finally, the liquid stream is either mixed with the light fraction to obtain upgraded oil, or both streams (the product from the reactors and light fraction from fractionation) can be sent to be utilized in the distillation of crude oil. The first option aims to produce better-quality upgraded oil for commercialization purposes (upstream sector), and the objective of the second option is to serve as a means of pretreating the crude oil before it enters the atmospheric distillation column in a refinery.

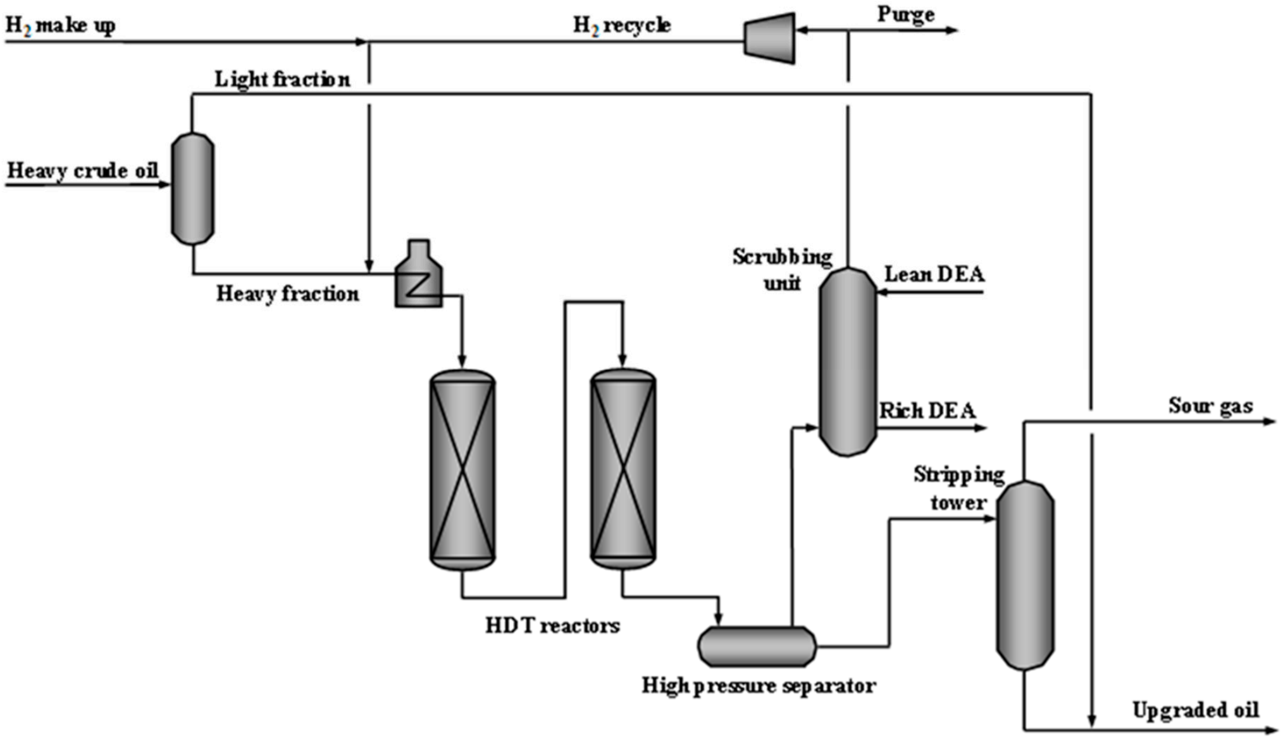

Figure 1. Simplified flow process diagram of HIDRO-IMP technology.

By working under moderate-reaction-severity conditions at mild conversion, the HIDRO-IMP technology can upgrade heavy and extra-heavy crude oils so that they can be transported and processed in conventional refineries, as well as sold at a higher price. The main characteristics of HIDRO-IMP, which make it different from other technologies, are as follows: operation at mild pressure and temperature; its use of in-series fixed-bed reactors with proprietary selective catalysts for the removal of metals (mainly nickel and vanadium) and sulfur; the hydrocracking of asphaltenes; mild conversion of vacuum residue fraction into valuable distillates with a volumetric expansion of 104–108%, depending on the heavy crude oil processed; low sediment formation; high removal of impurities present in the heavy oil feed (sulfur, nitrogen, metals, asphaltenes); low investment and operating costs; the upgrading of the heavy crude oil by increasing the yield of distillates; reduced viscosity; and the production of an upgraded oil with low acidity, corrosivity, and tendency to form coke. More detailed information about the HIDRO-IMP technology can be found in a recently published book [1].

The development of the HIDRO-IMP technology officially started in the year 1999. Some previous small projects for catalyst and process development were executed in the years 1990–1995, from which two Mexican patents were granted [2,3]. A timeline of all the stages of HIDRO-IMP technology development is shown in Figure 2. This can be considered the beginning of worldwide research on upgrading heavy crude oils, since before this date, nothing can be found in the literature regarding the processing of whole heavy crude oil via hydrotreating. There are, indeed, other commercial technologies already in use, but they are aimed at either the removal of sulfur or high-severity hydrocracking of the bottom of the barrel, i.e., atmospheric or vacuum residue.

Research and development stages were conducted during the years 1999–2003. Many short-term bench-scale tests were carried out with different heavy crude oils and hydrotreating catalysts. The catalysts were developed in our laboratories. The results obtained were presented to different authorities of the Mexican Oil company. At that time (~2004), petroleum production in Mexico was mainly composed of heavy crude oils (>50%), and the idea of converting them into light crude oil was of high interest. However, the level of experimentation (bench-scale) was questioned in terms of scaling-up the results, and a larger unit to conduct a semi-commercial demonstration test was recommended. Fortunately, we received a budget from the oil company to perform the requested semi-commercial test. Prior to this, a long-term experimental evaluation (~6 months) in a two fixed-bed bench-scale unit with crude oil having a 13°API was carried out. The main conclusions derived from this test latter were as follows:

✓ The activity and stability of the proprietary catalysts used for the hydrotreating of heavy crude oils with the HIDRO-IMP technology were successfully tested and demonstrated.

✓ The three-catalyst system allowed the hydrotreating reactions to remove the high content of metals in the first bed of reactor 1, and the other two catalysts were consequently protected from premature catalyst deactivation.

✓ The moderate-reaction-severity conditions used in the test (total pressure of 100 kg/cm^2, hydrogen-to-oil ratio of 5000 ft^3/Bbl of heavy oil entering the reactor, liquid hourly space velocity (LHSV) of 0.5 h^{-1}, and start-of-run temperature of 380 °C) were properly used. These reaction conditions are lower than other commercially available technologies and ensure the production of a constant API gravity in upgraded oil, with reduced contents of sulfur, asphaltenes, and metals.

✓ Working at such conditions also limits the residue conversion at values lower than 50%, thus keeping sediment formation low (<0.4 wt.%) and ensuring the continuous operation of the unit.

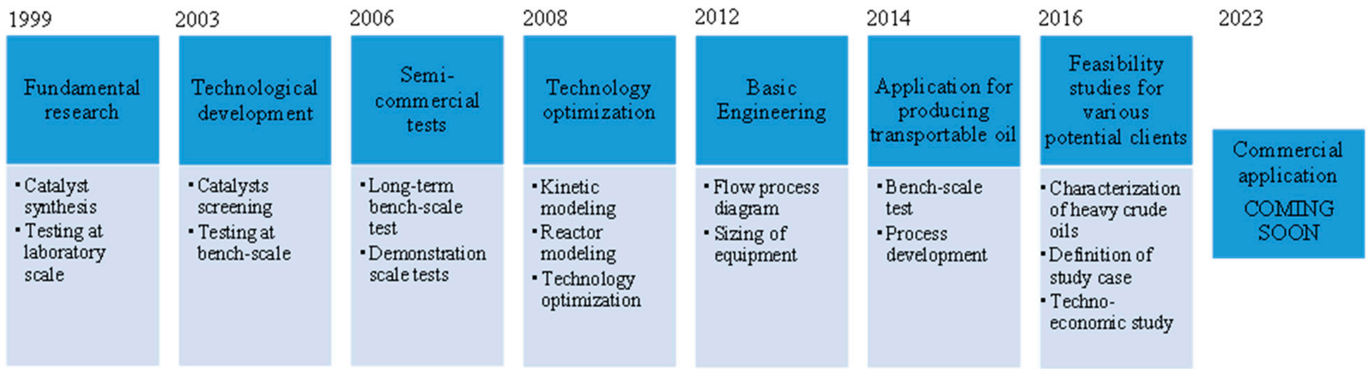

Figure 2. Stages of HIDRO-IMP process development.

Figure 3 depicts the relevant results of the long-term experiments. According to Figure 1, the feedstock for the HIDRO-IMP plant is heavy crude oil, and the feedstock for the first reactor is its atmospheric residue (AR). Figure 3 shows the API gravity values considering the two feedstocks, the heavy crude oil, and the AR.

Various patents related to the process [4–7] and catalysts [8–12] were granted, which include the use of the HIDRO-IMP technology for upgrading the fluidity properties of heavy crude oils for transportation via pipeline (HIDRO-IMP-T), the upgrading of heavy crude oils to produce light crude oils (HIDRO-IMP-U), the conversion of residue in a petroleum refinery (HIDRO-IMP-C), and catalysts for hydrodemetallization, hydrodesulfurization, and hydrocracking.

Once this long-term bench-scale test was properly developed and confirmed to be successful, a couple of demonstration tests in a 10 BPD unit were conducted (2006–2008). Figure 4 shows the main results of this demonstration scale test, from which the following main conclusions were obtained:

✓ The HIDRO-IMP-C technology was successfully demonstrated at the semi-commercial level.

✓ The API gravity of the heavy crude oil increased from 12.93 to 23.28°, while reductions in sulfur and metals contents were 77.8% (from 5.19 wt.% to 1.15 wt.%) and 83.2% (from 584 ppm to 98 ppm), respectively.

✓ Sediment formation was kept at low values while the continuous operation of the commercial plant was guaranteed.
✓ The catalysts demonstrated their high metal retention capacity and high selectivity towards hydrodesulfurization and hydrocracking reactions, thus producing a constant-quality upgraded oil, and ensuring acceptable runs of operation.

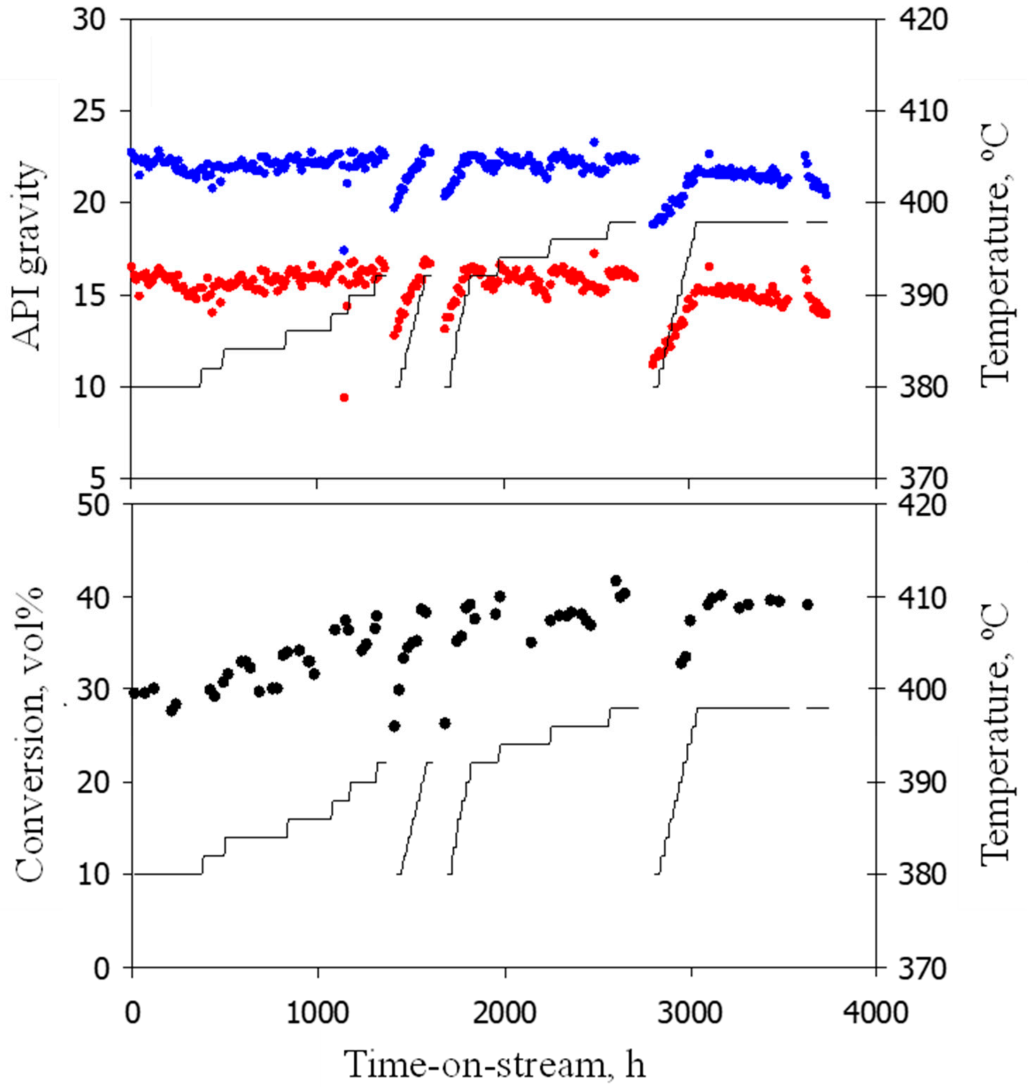

Figure 3. API gravity and conversion during the long-term test. (•) Upgraded oil (crude oil feed = 12.7° API), (•) Hydrotreated product (AR feed = 3.2° API), (•) Conversion, (—) reactor temperature.

The results of the semi-commercial test were presented and discussed again with the individuals in the oil company, but at that time (~2008), the situation of oil production in Mexico was more favorable, and the need to convert heavy crude oils into light crude oils was not as urgent as in previous years.

In the following years (2008–2012), the development of the HIDRO-IMP technology continued with some optimization studies and a basic engineering design. Some additional studies focused on reducing the viscosity of heavy crude oils to produce transportable oil, and experimental evaluations with different Mexican heavy crude oils were also conducted (2012–2015).

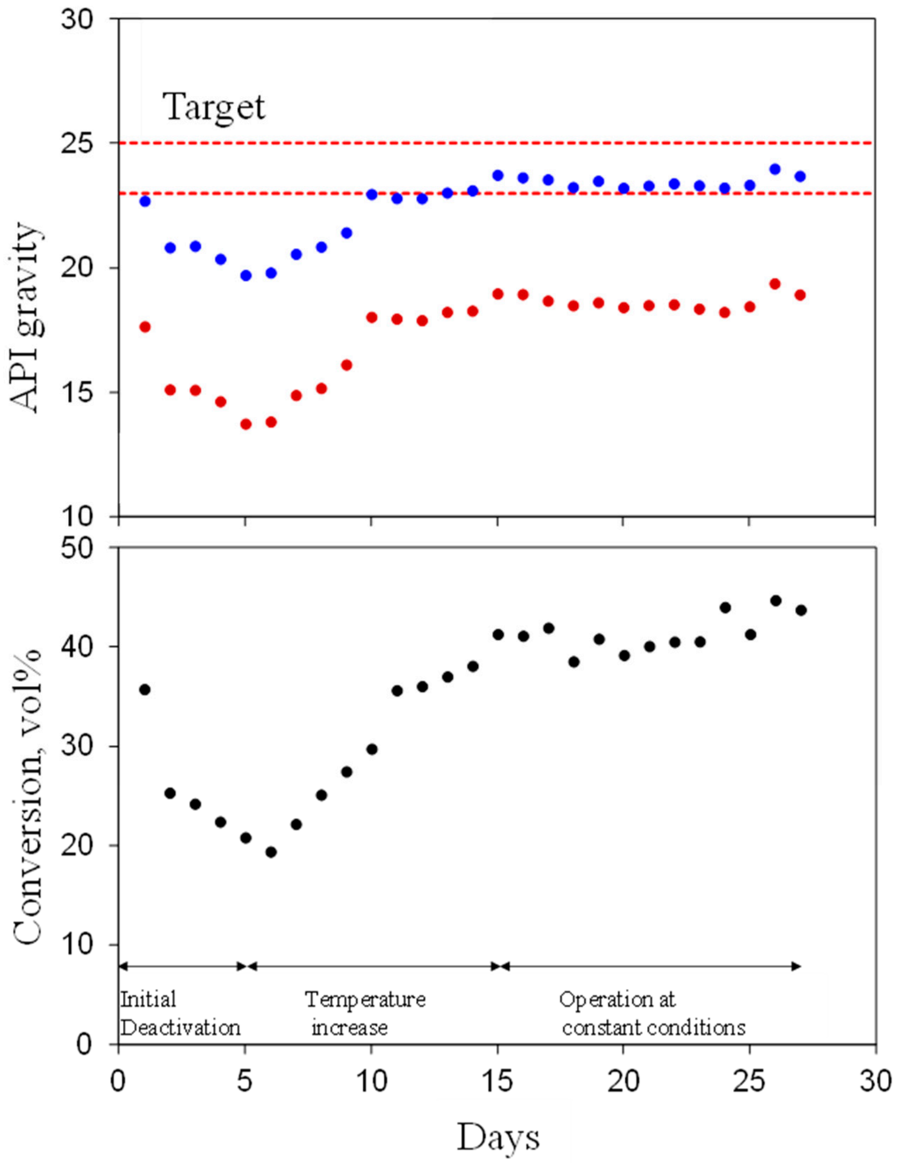

Figure 4. API gravity and conversion during the semi-commercial test (•) Upgraded oil (crude oil feed = 12.9° API), (•) Hydrotreated product (AR feed = 5.4° API), (•) Conversion.

Other clients outside Mexico were also identified, and techno-economic studies were conducted via simulation (2016–2018). It should be highlighted that with all the experimental information generated at different scales, operating conditions, and feedstocks, robust kinetic and reactor models were developed. The application of the HIDRO-IMP technology was clearly demonstrated to be an excellent alternative for the partial upgrading of heavy crude oils. The differences with other commercially available technologies that work at full conversion (ebullated-bed- and slurry-bed-based technologies) were clearly established, and no direct competition with them was identified. The HIDRO-IMP technology focuses on partial upgrading (around 50% conversion) at moderate-reaction-severity conditions, whereas others are based on full upgrading (70–95% conversion) at high-reaction-severity conditions. These differences make HIDRO-IMP a low-operating- and investment-cost technology, as is indicated in Figure 5. It was observed that producing high-quality upgraded oil (full upgrading) also requires high investment and operating costs, but this option does not yield the highest return of investment. On the contrary, partial upgrading, although not producing an oil with the high quality of full conversion technologies, gives the highest return of investment. To achieve this target, during HIDRO-IMP technology development, the main objective function was economics. In other words, every experimental study was accompanied by an economic analysis so that the optimal operating conditions, process scheme, and even the cut boiling point of the heavy oil sent to the first reactor were defined to minimize the investment and operating cost of the unit. It should be noted that Figure 5 remains the same regardless of the changes in prices of crude oil over time, since the economic analysis considers both the price of the crude oil and the price of the upgraded oil, and the differences between the two prices is kept more or less constant over the years; therefore, the economical parameters are not affected to a great extent.

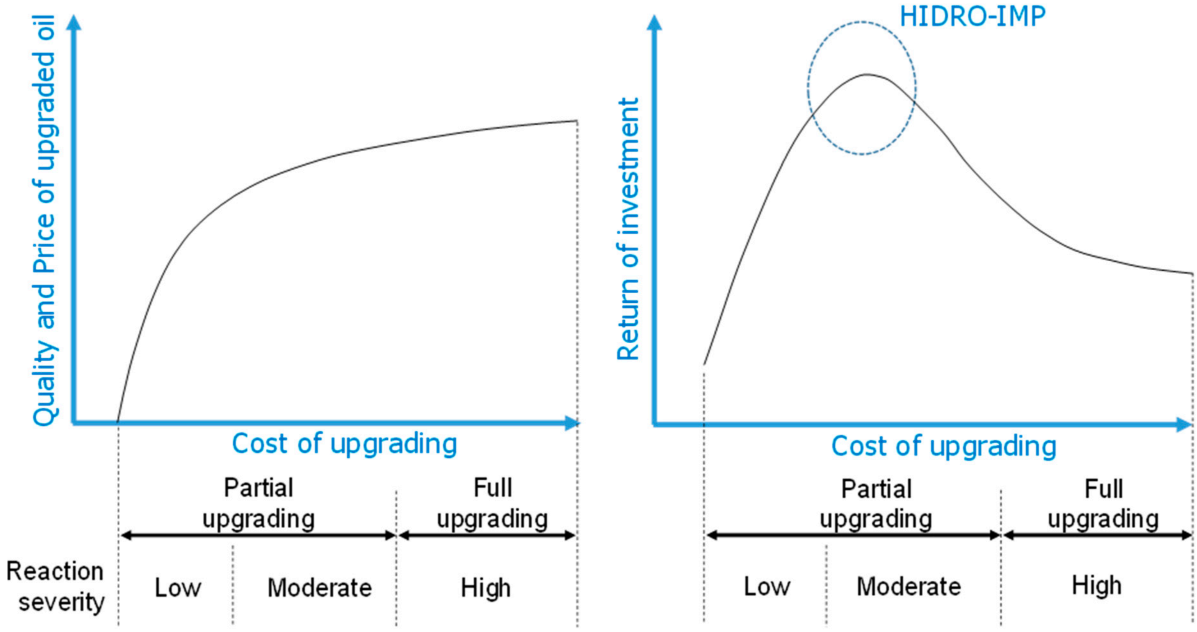

Figure 5. Economics of partial upgrading versus full upgrading of heavy crude oils.

Other companies (Genoil Inc. (Calgary, AB, Canada), Rigby Refining LLC (Houston, TX, USA), Gazprom Neft (Saint Petersburg, Russia)) and the University of Bradford developed similar technologies and were granted patents or published scientific papers after the publication of the HIDRO-IMP patent. Except for the Rigby process, which was designed to produce a marine fuel oil product, the other technologies have the same objective as HIDRO-IMP. The Ribby patents were granted in 2019 ("Heavy marine fuel oil composition") and in 2020 ("Process and device for treating high sulfur heavy marine fuel oil for use as feedstock in a subsequent refinery unit"). The Genoil patent was granted in 2014 ("Process for treating crude oil using hydrogen in a special unit"). These patents were granted by the US patent office. Gazprom Neft is promoting a hydroconversion technology ("Hydroprocessing of heavy residues"), but the associated patent was not found; surely it was granted in Russia. In the case of the University of Bradford, the researchers published a series of papers dating back to 2011 as part of a PhD thesis. It was confirmed with them that no patents were granted. In one of their papers, they stated that the hydrotreating of whole crude oil was reported for the first time, which is obviously an erroneous statement, since our first Mexican patent ("Procedure for hydrotreating of heavy crude oils to produce synthetic oil") was granted in 1995 and our first US patent was granted in 2010 ("Process for the catalytic hydrotreatment of heavy hydrocarbons of petroleum"). Both HIDRO-IMP technology patents were granted before this academic group published their papers.

This clearly indicates that the Mexican Institute of Petroleum has been a pioneer in the area of the upgrading of heavy and extra-heavy crude oils. Like us, these other developments have not been introduced at a commercial level yet. To do so, apart from the corresponding questions of intellectual property, hydrotreating catalysts must be tested at different conditions to define the operating window in which the process can operate without sediment formation problems. In addition, long-term experiments are mandatory to verify the metal retention capacity of the catalyst, particularly the front-end catalyst, which is designed with optimized pore size distribution to maximize the accumulation of metals (vanadium and nickel) and protect the following catalyst from premature deactivation. And, not only this, but the experimentation must also be scaled-up to a semi-commercial level in order to confirm the laboratory experimental results; techno-economic studies must be developed as well in order to keep the economics of the technology as attractive as possible. To offer a technology for possible commercial applications, basic engineering is necessary at least, and the cost of all the unit components must be determined. All these steps have already been developed for the HIDRO-IMP technology. In other words, it is already available for commercial application.

3. Combination of HIDRO-IMP with Delayed Coking

Given that the commercial application of the HIDRO-IMP technology on its own was delayed longer than expected, its combination with a delayed coking process was evaluated for partial bottom-of-the-barrel conversion, and the remaining unconverted residue was then processed in a coker unit [13]. The main idea for this combination was that many current refineries around the world have a delayed coking unit as a bottom-of-the-barrel conversion process. However, when processing heavier crude oils in a refinery, the amount of produced vacuum residue is high, and it exhibits a high content of sulfur and metals, which reduces the quality of the coke. Also, the high content of Conradson carbon residue increases the production of coke. For instance, for a 22°API crude oil, the liquid product yield is about 90 vol.%, and the yield of coke is 12 wt.%, whereas for a 16°API crude oil, they are 80 vol.% and 22 wt.%, respectively. This means that the heavier the crude oil, the higher the production of coke and the lower the volumetric liquid product yield. Using the HIDRO-IMP technology before a delayed coker unit can yield better performance. For example, the hydrotreated residue would exhibit lower amounts of metals and sulfur, so that the feed to the delayed coker would be of higher quality, and all the coker products, i.e., coker naphtha and gas oil, would exhibit reduced concentrations of sulfur and would have less of an aromatic nature, which would allow them to become better feed components for producing low sulfur gasoline and diesel. Also, the coke would be lower in sulfur and metals and could be used to produce better products.

From the study of the combination of HIDRO-IMP technology with delayed coker units, the main results were as follows:

- ✓ HIDRO-IMP plus delayed coking yields the highest economic benefits.
- ✓ The results of HIDRO-IMP alone were better than from delayed coking alone.
- ✓ Other advantages of combined HIDRO-IMP plus delayed coking are zero production of fuel oil, high-quality feed and products that would require null or less-severe further hydrotreating (coker naphtha and gas oil), lower production of coke, and the production of coke with reduced metal and sulfur content.
- ✓ It proved evident that the combination of HIDRO-IMP plus delayed coking presents advantages for refineries that do not have a process for bottom-of-the-barrel conversion or those that only have a delayed coker unit.

The technical and economic benefits that have been previously commented on are only for the HIDRO-IMP technology itself; however, the upgraded oil produced when processed in a refinery can yield the following additional benefits in different conversion processes compared with a typical refinery feed without hydrotreating:

- ✓ The hydrodesulfurization of gas oil: Gas oil coming from the distillation unit would have a reduced concentration of sulfur and other impurities. It would also be partially hydrogenated so that the required operating conditions to achieve the ultra-low sulfur specification would be less severe (lower start-of-run temperature, higher space velocity). This would increase the life of the catalyst; i.e., the starting operation at a low reaction temperature would increment the operating temperature window and reduce energy consumption in order to heat up the feed, with a consequent reduction in operating costs.

✓ Fluid catalytic cracking of vacuum gas oils: The same benefits of better-quality feed would be obtained in catalytic cracking, i.e., reduced amount of sulfur, nitrogen, and metals, as well as less aromatic content. These better properties would positively influence the catalytic cracking unit. For instance, low amount of metals would produce low amount of gases, and, as the compressor could work at more capacity so could the catalytic cracking unit. It would also reduce the catalyst deactivation rate and fresh catalyst addition; catalytic gasoline and light cycle oil would be better feed components for naphtha and gas oil hydrodesulfurization units, and heavy cycle oil could be used as better-quality diluents for producing low sulfur fuel oil.

The spent catalysts from the HIDRO-IMP technology, which would be highly concentrated in metals such as vanadium and nickel, could be used for further rejuvenation or metal recovery. There are plenty of companies that would benefit from these used catalyst samples. In fact, when I was looking for a catalyst manufacturer, a company offered me fresh catalysts for free if, after finishing the operation of the plant, I gave the spent samples back to them.

It should also be highlighted that the HIDRO-IMP technology is focused on the use of hydrotreating technology for the upgrading of heavy crude oils. These heavy crude oils are characterized by having a low H/C ratio; that is, they are deficient in hydrogen and highly concentrated in carbon. To decarbonize the refining industry, this type of technology is necessary so that the carbon fingerprint can be reduced to achieve net zero emissions.

In summary, the HIDRO-IMP technology has been subject to all the possible experimental tests and studies that could guarantee its commercial application, which I expect could be soon.

4. Conclusions

Although the HIDRO-IMP technology has been tested at different experimentation scales, including two semi-commercial tests, has been evaluated for the upgrading of various heavy and extra-heavy crude oils, has had various positive techno-economic studies performed on its benefits, has robust kinetic and reactor models developed for the prediction of the process's performance, and indicates that preliminary basic engineering is already available, its commercial application is still under negotiation. The main reason for such an indecision of people in refinery is that they feel more comfortable with already-proven technologies. To overcome this situation, it is recommended that people in refinery be involved in a technology's development from early research stages so that they can provide not only information but also guidance to adjust the technology to real-life requirements. There should also be a compromise between the research center and the end user to apply the developments at the commercial scale. This is why, from a research point of view, nobody wants to be the first for the commercial application of new technologies.

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Conflicts of Interest: Author Jorge Ancheyta was employed by the company Instituto Mexicano del Petróleo. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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