DOI: 10.18454/PMI.2017.2.229

UDC 665.637.3

HYDRO-IMP TECHNOLOGY FOR UPGRADING OF HEAVY PETROLEUM

JORGE ANCHITA
National Polytechnic Institute, Mexican Petroleum Institute, Mexico City, Mexico

Hydroprocessing is one of the most important processes in petroleum refining industry, not only for upgrading of heavy oils but also for producing low-impurity content fuels and preparing feeds for various conversion processes. Experimental results obtained in pilot plant and semi-commercial scales for hydroprocessing of heavy oils are reported in this work. Mexican heavy crude oils (10, 13 and 16°API) with high amount of impurities were used for all tests. Hydroprocessing was conducted at moderate reaction severity in two fixed-bed reactors in series. Removals of sulfur, metals and asphaltenes, as well as changes of API gravity and viscosity were monitored at different reaction conditions with time-on-stream. Upgraded oils with reduced amounts of impurities and increased API were obtained, keeping sediment formation below maximum allowable content. Removal of impurities was higher in semi-commercial scale compared with pilot plant test. Have been proved that the heavier the feed the greater the gain in product quality. For instance, 10°API crude can increase its gravity up to ~22°API (Δ°API = 12), while 16°API crude increases its gravity up to ~25°API (Δ°API = 9). Sediment formation was also kept below 0.05 wt % and no other problems (excessive reactor delta-P, plugging, etc.) were observed during the test.

Key words: hydroprocessing, heavy oil, upgraded oil

How to cite this article: Jorge Anchita. HYDRO-IMP Technology for Upgrading of Heavy Petroleum. Zapiski Gornogo instituta. 2017. Vol. 224, p. 229-234. DOI: 10.18454/PMI.2017.2.229

Introduction. The worldwide energy consumption is growing year by year. Petroleum currently represents 33 % of the total world energy supply [8] and by far is the most commonly used source of liquid fuels.

It is expected that this scenario will continue for the next 50 years [1, 2]. Figure 1 shows how the world consumption of oil-refining products has been increasing during the last 20 years. In particular, the last decade has witnessed a 12.2 % growth in petroleum product usage. This behavior is owed to the fast-developing demand for automotive and aviation fuels, particularly in developing countries such as China, Russia, and Latin America [7].

The increasing heavy crude production calls for new methods for the preparation and processing. Heavy crudes contain a significant amount of resins, asphaltenes, and heterocompounds, which negatively affects not only the quality of oil products, but also the performance of the equipment. Another distinguishing characteristic of heavy oils is their high viscosity that can reach 10000 mPa·s [6].

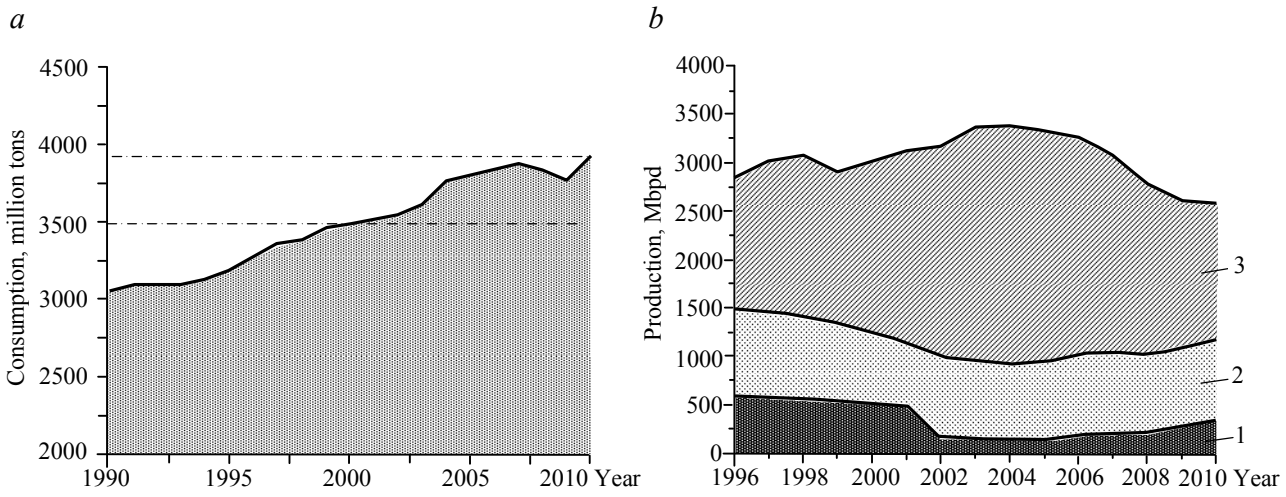


Figure 1. World consumption of oil-refined products (*a*), crude oil production in Mexico (*b*)
1 – Superlight; 2 – Light; 3 – Heavy

DOI: 10.18454/PMI.2017.2.229

There are a lot of research, which try to find best way of heavy oil processes, one of them is method, which includes deasphalting process, hydrotreating, delayed coking, demetallization and thermodestructive processes or gasification [10].

Hydroprocessing is a mature technology practiced in the petroleum refining industry for the upgrading of hydrocarbon streams for the last 60 years. It is a fundamental refining process for the upgrading of a wide variety of streams, ranging from straight-run naphtha to vacuum residue or even heavy and extra-heavy crude oils [9]. By means of hydroprocessing heavy petroleum could be converted into lighter products with simultaneous removal of sulfur, metals, and asphaltenic compounds from the feedstock. In the past, it was believed that hydroprocessing seemed to be not economical for application to upgrading of heavy petroleum. At least two factors dampened interest: the high cost of hydrogen and the adequacy of current practices for meeting the demand for high-value products by refining conventional crude oil. Heavy oils and residua are generally considered to be low-value feedstocks by the refining industry. Hence they are the focus of many conversion scenarios. Indeed, there has been a tendency for the quality of crude oil feedstocks to deteriorate insofar as the average refinery feedstock is of lower API gravity and higher sulfur content than the average refinery feedstock of two decades years ago. This means higher quantities of residua and more heavy oils to process.

There are several valid reasons for using hydrogen to process heavy oils; these include: reduction, or elimination, of sulfur from the products; production of products having acceptable specifications; increasing the performance (and stability) of gasoline; decreasing smoke formation in kerosene; improvement in the burning characteristics of fuel oil to a level that improves burning characteristics and is environmentally acceptable [4].

Generally, over the past three decades, we have seen emerge a growing dependence on high-sulfur heavier oils and residua as a result of continuing increases in the prices of the conventional crude oils coupled with the decreasing availability of these crude oils through the depletion of reserves in the various parts of the world. Furthermore, the ever growing tendency to convert as much as possible of lower grade feedstocks to liquid products is causing an increase in the total sulfur content in refined products. Refiners must, therefore, continue to remove substantial portions of sulfur from the lighter products, but residua and the heavier crude oils pose a particularly difficult problem. Indeed, it is now clear that there are other problems involved in the processing of the heavier feedstocks and that these heavier feedstocks, which are gradually emerging as the liquid fuel supply of the future, need special attention.

Hydroprocessing petroleum fractions has long been an integral part of refining operations, and in one form or another, hydroprocesses are used in every modern refinery. The process is accomplished by the catalytic reaction of hydrogen with the feedstock to produce higher value hydrocarbon products. The technology of hydroprocesses is well established for gas oil and lower boiling products but there is no comprehensive source of information for hydroprocessing heavy crude oils and residua. Indeed, processing heavy oils and residua present several problems that are not found with distillate processing and which require process modifications to meet the special requirements that are necessary for heavy feedstock desulfurization [5].

The aim of the present contribution is to show general aspects of a process developed in Mexico for upgrading of heavy oils and residua. Hydroprocessing in fixed-bed reactor operating at moderate reaction severity is demonstrated to be technically and economically attractive to upgrading of Mexican heavy oils.

Characteristics of HYDRO-IMP Process. The Mexican Institute of Petroleum has developed a catalytic process (HYDRO-IMP) whose main objective is the upgrading of heavy and extra-heavy crude oils. HYDRO-IMP technology can produce low-impurities content (sulfur, metals, asphaltenes) upgraded oils, easy-to-refine and with increased market price [3].

DOI: 10.18454/PMI.2017.2.229

HYDRO-IMP process is based upon the catalytic hydrotreatment/hydrocracking of the heavy oil at moderate operating conditions, and achieves high removal of metals, sulfur, nitrogen and asphaltenes as well as significant conversion of the heavier portions of the feedstock to more valuable distillates, while keeping the formation of sediments and sludge at very low levels. The most important characteristics of this process are relatively low investment and operating costs and an attractive return of investment.

The main applications of HYDRO-IMP process are:

– moderate conversion of heavy and extra-heavy crude oils to intermediate crude oils of higher value in the market;

– partial conversion of heavy and extra-heavy crude oils to produce transportable oils by reducing viscosity;

– conversion of residue in a refinery.

A simplified flow diagram of HYDRO-IMP process is shown in Figure 2. The initial step involves splitting a full boiling range heavy crude oil (HCO) into a light fraction and a heavy fraction (typically an atmospheric residue [AR]). The heavy fraction is subjected to hydroprocessing conditions in a first fixed-bed reactor, where the removal of substantial metals and asphaltenes 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 hydrodesulfurization (HDS) and hydrodenitrogenation (HDN), and a moderate level of HCR. 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 in order to remove the remaining dissolved hydrogen sulfide. The gas mixture from the high-pressure separator is fed to the scrubbing unit in order to remove hydrogen sulfide and ammonia, and the resulting high hydrogen purity stream is recompressed and recycled to the reaction system. Finally, either the liquid stream is mixed with the light fraction to obtain the upgraded oil or both streams (product from the reactors and light fraction from fractionation) can be sent to distillation of crude oil. The first option aims at producing better quality upgraded oil for commercialization purposes (upstream sector), and the objective of the second option is to pretreat the crude oil before it enters the atmospheric distillation column.

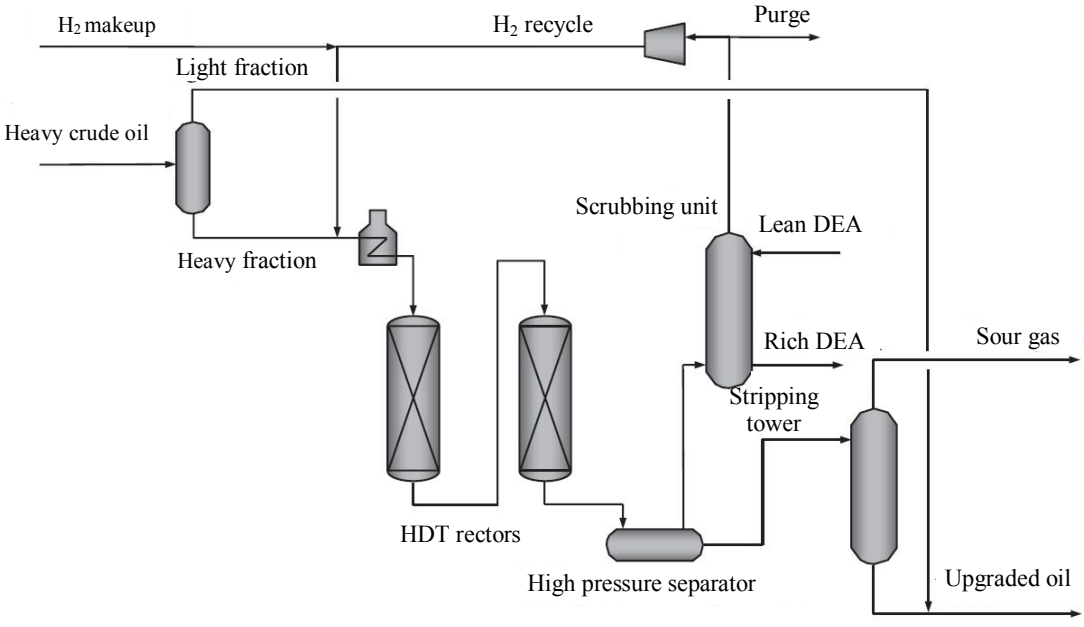


Figure 2. Simplified representation of HYDRO-IMP process for upgrading of heavy oils and residua

DOI: 10.18454/PMI.2017.2.229

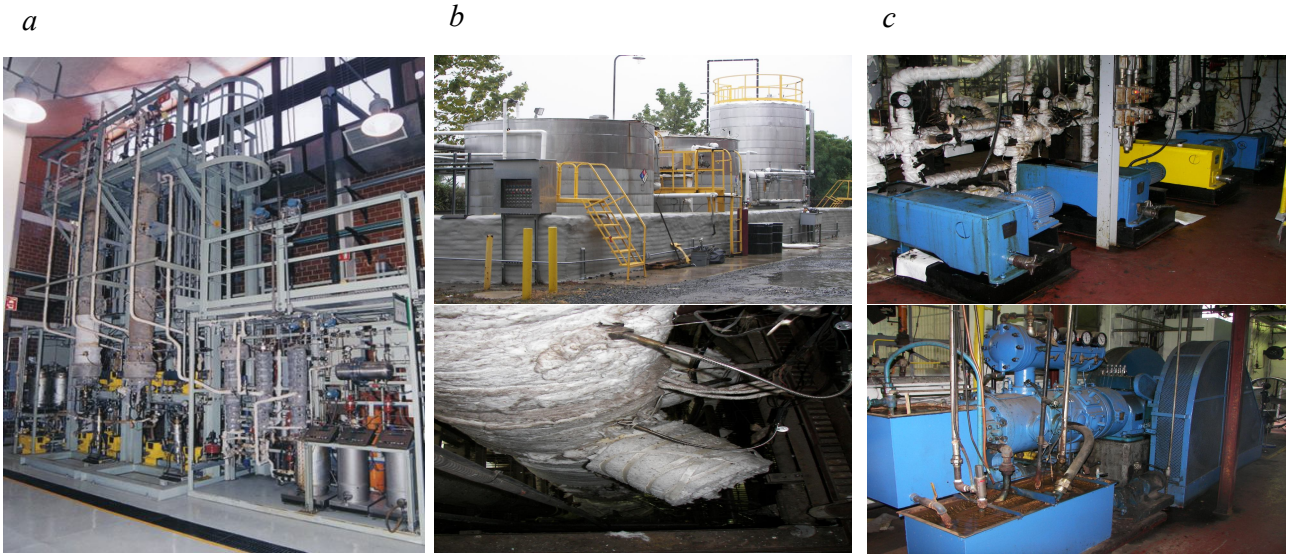


Figure 3. General views of experimental units
a – pilot plant; *b*, *c* – some sections of the semi-commercial plant

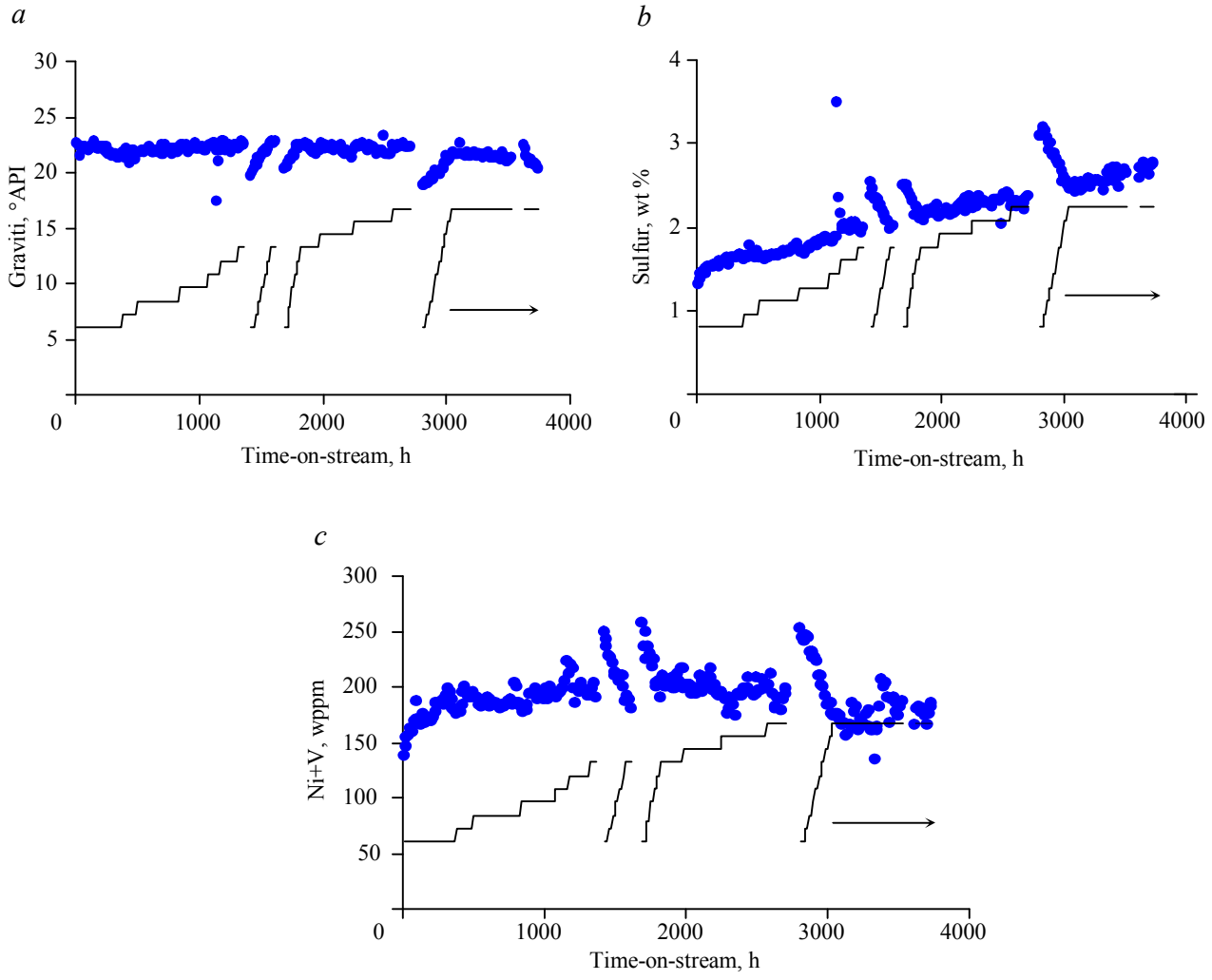


Figure 4. Experimental results obtained in pilot plant scale
a – °API = 12,71; *b* – Sulfur in feed = 5.22 wt%; *c* – (Ni + V) in feed = 507 wppm

DOI: 10.18454/PMI.2017.2.229

Results And Discussion. Hydroprocessing of heavy petroleum (13°API) was conducted in a pilot plant located at the facilities of the Mexican Institute of Petroleum. The main characteristics of this plant are: two fixed-bed reactors in series, 500 mL catalyst per reactor, isothermal operation, and about 1 BPD capacity. Semi-commercial test was carried out in a ~ 10 BPD capacity plant located in New Jersey, USA. General views of both the pilot plant and the semi-commercial unit are presented in Fig.3.

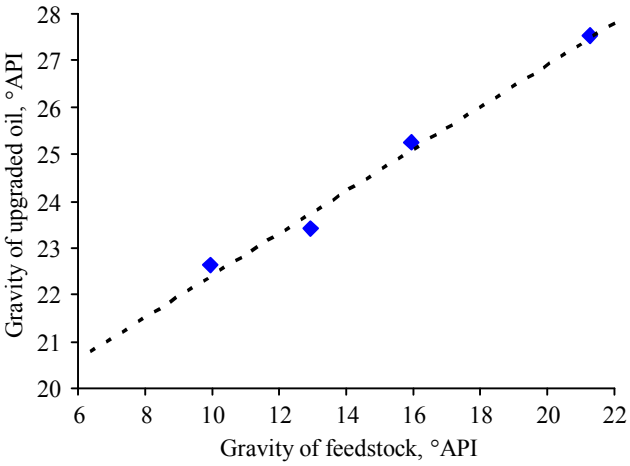


Figure 5. API gravity of upgraded oil as function of API of the feedstock

Pilot plant results about changes in API gravity, sulfur and metals contents as function of time-on-stream are reported in Fig.4. This long-term test lasted about 5 month, during which no problems with sediment formation were observed, since it was maintained always below 0.05 wt %. Some minor operational issues were presented during the experiment, which were immediately corrected. Reactor temperature was continuously adjusted to produce upgraded oil with constant API gravity (21-22°API) from a feed with about 13°API. Important reductions in sulfur content (from 5.22 to ~2-2.5 wt %) and metals (Ni + V) content (from 507 to ~ 200 wppm) were obtained.

The results obtained at semi-commercial scale using the same feed (13°API crude), catalysts and operating conditions were in good agreement with those obtained at pilot-plant scale. In fact, removal of impurities was higher in semi-commercial scale compared with pilot plant test (sulfur reduced to 1.1 wt % and metals to 98 wppm). Other heavy oils were also evaluated at semi-commercial scale and similar behaviors in the different reactions were obtained. Representative results of the changes in API gravity at semi-commercial level and similar reaction conditions are depicted in Fig.5. It can be seen that the heavier the feed the greater the gain in product quality. For instance, 10°API crude can increase its gravity up to ~22°API (Δ°API=12), while 16°API crude increases its gravity up to ~25°API (Δ°API=9). Sediment formation was also kept below 0.05 wt % and no other problems (excessive reactor delta-P, plugging, etc.) were observed during the test.

Conclusions

1. Technical and economical studies carried out to evaluate the application of this technology in a heavy crude oil upgrader and in a typical refinery scheme show important advantages of HYDRO-IMP process in comparison with the main technologies commercially available for bottoms-of-the-barrel processing.

2. The improvements in the quality of heavy crude oils obtained by applying HYDRO-IMP technology include higher yields of distillates, lower contents of sulfur, metals, asphaltenes and coke formation precursors, lower acidity, corrosivity, viscosity and deposits formation tendency. These characteristics facilitate handling, transportation and refining of heavy and extra-heavy crude oils and increase their value in the market.

3. The results obtained at semi-commercial scale using the same feed (13°API crude), catalysts and operating conditions were in good agreement with those obtained at pilot-plant scale.

DOI: *10.18454/PMI.2017.2.229*

4. Removal of impurities was higher in semi-commercial scale compared with pilot plant test (sulfur reduced to 1.1 wt % and metals to 98 wppm).

5. The heavier the feed the greater the gain in product quality. For example, 10°API crude can increase its gravity up to ~22°API (Δ°API=12), while 16°API crude increases its gravity up to ~25°API (Δ°API=9). Sediment formation was also kept below 0.05 wt % and no other problems (excessive reactor delta-P, plugging, etc.) were observed during the test.

REFERENCES

1. Ancheyta J., Speight J.G. Heavy oils and residua. Chapter 1. In Hydroprocessing of Heavy Oils and Residua. CRC Press, Taylor & Francis, Boca Raton. FL, 2007, p.17-30.

2. Ancheyta J., Speight J.G. Hydroprocessing chemistry. Chapter 3. In Hydroprocessing of Heavy Oils and Residua. CRC Press, Taylor & Francis, Boca Raton. FL, 2007, p.52-68.

3. Ancheyta J., Centeno G., Trejo F., Marroquin G. Changes in asphaltene properties during hydrotreating of heavy crudes. *Energy Fuels*. 2003. N 17(5), p. 1233-1238.

4. Alvarez A., Ancheyta J. Modeling residue hydroprocessing in a multi-fixed-bed reactor system. Appl. Catal, 2008. N 351(2), p. 148-158.

5. Alvarez A., Ancheyta J., Centeno G., Marroqui G. A modeling study on the effect of reactor configuration on the cycle length of heavy oil fixed-bed hydroprocessing. *Fuel*. 2011. N 90(12), p. 3551-3560.

6. Boitsova A., Kondrasheva N. Changes in the properties of heavy oil from yarega oilfield under the action of magnetic fields and microwave radiation. *Theoretical Foundations of Chemical Engineering*. 2016. Vol. 50. N 5, p. 847-851.

7. Enerdata. *Global Energy Statistical Yearbook*. 2011. Available at: http://www.enerdata.net.

8. International Energy Agency. Key world energy statistics. 2010. Available at: http://www.iea.org.

9. Jimenez F., Ojeda K., Sanchez E., Karafov V., Maciel R. Filho Modeling of trickle bed reactor for hydrotreating of vacuum gas oils: Effect of kinetic type on reactor modeling. Ed. V.Plesu, P.S.Agachi. In 17th European Symposium on Computer Aided Process Engineering – ESCAPE17. Elsevier BV, Amsterdam, the Netherlands, 2007, p.247.

10. Kondrasheva N., Vasilyev V., Boytsova A. Research the possibility of obtaining high-quality petroleum coke from heavy Yaregskaya oil. *Chemistry and Technology of Fuels and Oils*. 2016. N 6, p.14-18.

Author **Jorge Anchita**, *Doctor of Engineering Sciences*, *Professor*, *Head of the Project*, *jancheyt@imp.mx* (*National Polytechnic Institute, Mexican Petroleum Institute, Mexico City, Mexico*).

The paper was accepted for publication on 30 November, *2016.*