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A Petroleum Refining Course in Chemical Engineering*

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This paper describes the importance of 'petroleum refining' in chemical engineering curricula. Detailed information on course syllabus, a variety of assignments and a summary of laboratory equipment used in analyzing various properties of petroleum products are presented. Selected references and publications related to petroleum refining courses are also included.

INTRODUCTION

REFINING crude oil is the art of choosing the crude oils and of using the flexibility of the refinery processes available, in order to provide products suitable for market requirements. Today, petroleum is the source of hundreds of products, ranging from gases and volatile liquids to bitumen and solid waxes [1]. It is also the source of hydrocarbon feedstocks for the vast petrochemical industry. Besides distillation, there are now several other separation processes and there are a variety of conversion processes that alter the chemical nature of the material. Moreover, these processes give considerable control over the quality and output of products for sale, making them less dependent upon the nature of the crude oil.

The State of Kuwait and other Gulf Cooperation Council countries have a large share of the world's oil production as well as the future oil reserve. Their entire economy is based on oil industries, and the Gulf countries have invested heavily in building large refining plants. The history of crude oil discovery started in 1936 but the actual production was from 1938 onwards [2]. There is high demand for Kuwait crude oil which is intermediate paraffinic in nature and yields a complete range of good-quality products. The demand for distillate products under present conditions grows proportionally more than the demand for heavy fuel, and this is expected to continue as far as can be foreseen.

In fact, the main industry in Kuwait is crude oil refining. There is a very strong demand for a substantial number of professionally qualified men and women to manage and supervise the planning, construction, modification and operation of the existing and future petroleum refining plants. In designing a refinery or an extension to an existing one, there must be a clear idea of what it has to achieve in terms of quantity and quality and how many surpluses will be disposed or deficits made good.

Many graduates of chemical engineering from Kuwait University are working in the field of petroleum refining. Their involvement in the functioning of the refinery varies from design, operation, maintenance, programming, scheduling, research and development, etc. In any event the technical department is responsible for the assessment of plant performance and day-to-day troubleshooting. In order to create student awareness of various refinery techniques, it is necessary to concentrate on the detailed analysis of the most widely used refining processes. Due to the above-mentioned factors, the Chemical Engineering Department at Kuwait University offers a compulsory petroleum refining course. During the course the students get an opportunity to visit the refineries and study the problems. Moreover, department invites visiting lecturers from refineries to talk about the new developments in petroleum refining processes and discuss the problems they are facing. This helps the students to take up the open-ended problems as case studies. This also encourages 15% of the graduates to take up research on different aspects in petroleum refining. Table 1 shows the current chemical engineering curriculum (in Kuwait University). This paper presents the petroleum refining course offered by the Chemical Engineering Department of Kuwait University.

The process flow diagram and products for a complete refinery of high complexity are shown in Fig. 1 [3]. The crude oil is heated in a furnace and charged to an atmospheric distillation tower, where it is separated into butanes and lighter wet gas, unstabilized full-range gasoline, heavy naphtha, kerosene, heavy gas oil and topped crude. The topped crude is sent to the vacuum tower and separated into vacuum gas oil overhead stream and reduced crude bottoms. The reduced crude bottoms from the vacuum tower is thermally cracked in a delayed coker to produce wet gas, coker gasoline, gas oil and coke.

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Table 1. Current chemical engineering curriculum

University requirements (15)		
0688-121	English	3
or		
0688-123	Remedial Practice and Writing skills	3
0688-221	Technical Writing	3
Students requiring remedial English must take:		
0688-098	(10 contact hours)	–
0330-102	History of Arab and Islamic Civilization	3
Humanities and Social Sciences		6
College requirements (58)		
0410-101	Calculus I	3
0410-102	Calculus II	3
0410-111	Linear Algebra	3
0410-211	Calculus III	3
0410-240	Ord. Diff. Eqns.	3
0420-113	General Chemistry	4
0430-101	Physics I	3
0430-105	Physics I Laboratory	1
0430-102	Physics II	3
0430-107	Physics II Laboratory	1
0600-102	Workshop	1
0600-104	Eng. Graphics	2
0600-200	Computer Programming	3
0600-202	Statics	3
0600-203	Dynamics	3
0600-204	Strength of Materials	3
0600-206	Elec. Eng. Fundamentals I	4
0600-208	Eng. Thermodynamics I	3
0600-209	Eng. Economy	3
0600-304	Eng. Probability and Statics	3
0600-308	Numerical Methods for Engrs	3
Department requirements (71)		
Compulsory courses (59)		
ChE 211	Chemical Eng. Principles I	3
ChE 212	Chemical Eng. Principles II	3
ChE 214	Physical Chemistry	3
ChE 241	Fluid Mechanics	3
ChE 242	Fluid Mechanics Laboratory	1
ChE 321	Chemical Eng. Thermodynamics	3
ChE 324	Kinetics and Reactor Design (A)	3
ChE 343	Heat Transfer	3
ChE 344	Heat Transfer Laboratory	1
ChE 351	Process Dynamics & Control	3
ChE 352	Process Control Laboratory	3
ChE 425	Kinetics and Reactor Design (B)	2
ChE 440	Mass Transfer Operation	3
ChE 442	Mass Transfer Operation Laboratory	2
ChE 461	Desalination	3
ChE 471	Gas Engineering	3
ChE 472	Refinery Engineering	3
ChE 491	Plant Design	3
ME 241	Mat. Science and Metallurgy	3
CHEM 234	Analytical Chemistry	3
CHEM 269	Organic Chemistry	4
Elective courses (12)		
Students choose 12 credits from the list of departmental selectives. However, a maximum of three credits may be substituted, with the approval of the department, by a suitable selection from science or engineering offerings.		
Total = 144		

The gasoline streams from the crude tower, coker and cracking units are fed to the catalytic reformer to improve their octane numbers. The products from the catalytic reformer are blended into regular and premium gasoline for sale. The alkylation uses either sulfuric acid or hydrofluoric acid as a catalyst to react olefins with isobutane to form isoparaffins boiling in the gasoline range. The product is called alkylate, and is a high-octane product blended into premium motor gasoline and aviation gasoline [3].

Each refinery has its own unique processing scheme which is determined by the equipment available, operating costs and product demand. The optimum flow pattern for any refinery is dictated by economic considerations and no two refineries are identical in their operations. Kuwait's refining capacity had reached around 750,000 barrels per day before the Iraqi invasion, but at the moment it is in the region of 500,000 barrels/day.

In a complex refinery most products are a blend of several streams and there is a certain flexibility in deciding how each refinery stream is divided amongst the outgoing products. This can be accomplished by adjusting the operating conditions, temperature, pressure, residence time on catalyst, heat input to furnaces, etc. [4].

COURSE DESCRIPTION

Kuwait University opened the college of Engineering and Petroleum in 1975. Graduate programs leading to M.Sc. degrees were introduced in 1985. Since its establishment in 1975, about 2100 students have graduated with B.Sc. degrees and more than 110 with an MSc. in the various engineering disciplines offered. The Faculty of Engineering has many divisions and is governed by the Dean. Chemical engineering is one of these divisions and is headed by a chairman. Presently, the teaching staff consist of 14 professors, of which 10 are of Kuwait nationals and the rest are expatriates. All the professors and associate professors have doctorates in chemical engineering from well-regarded universities in the United States and Europe. These professors are assisted by 14 non-teaching staff. All of them have a master's degree in chemical engineering and are mostly graduates from the United Kingdom.

In order to enhance the learning process the department has well-equipped laboratories, libraries and computers with the latest software. The department collaborates with technical consultants for the design and development of some projects. It also conducts seminars on various subjects relating

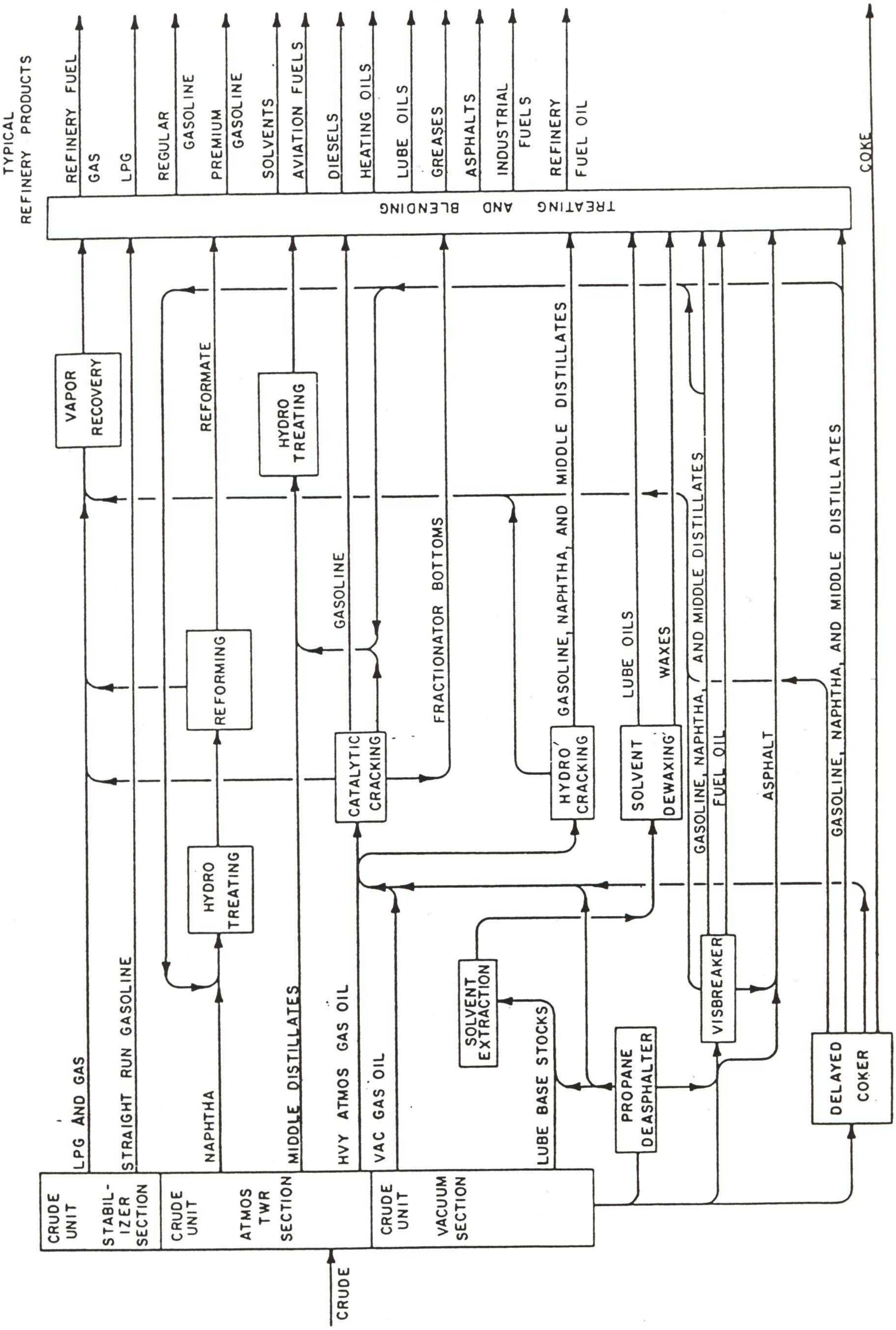

Fig. 1. Refinery flow diagram.

to the environment and industry. The main objectives of the courses are preparing high-quality engineers capable of assuming professional careers in industry and of playing a constructive role in solving the country's problems through applied research and consultation.

Every year about 90 students are admitted into the Chemical Engineering Department alone. The total strength of this department is 360 students, of which 33% are female. There is a withdrawal of approximately 5% of students every year. There is a total of 193 students on the department courses, of which 151 are department students and 42 are college students in department courses. The ratio of teaching staff to students is 1:13. Graduation of the course requires a minimum of 144 credits. The detail of this is presented in Table 2. Post-graduates must produce a thesis and require 36 credits.

Table 2. Classification of chemical engineering curriculum at Kuwait University

Category	No. of credits
Mathematics and Basic Science	48
Engineering Science	49.5
Engineering design	17
Humanities and Social Science	16.5
Others	13
Total	144

One of the prerequisites for the ChE 472 petroleum refining course is the study of the organic chemistry of petroleum products since both natural gas and crude oil are mixtures of numerous compounds called hydrocarbons. Another important prerequisite is mass transfer operations, which is a standard course covering the following topics: binary and multicomponent distillation, equilibrium flash distillation, solvent extraction, evaporation, drying, crystallization and mass transfer with chemical reaction. The prerequisites for ChE 472 can be summarized as follows:

1. Principles of material and energy balances.
2. Organic chemistry—formula of hydrocarbons, properties of individual compounds such as density, refractive index, viscosity, specific heat, critical properties, boiling point, vapor pressure, etc.
3. Reaction kinetics and reactor design, catalytic reactor, effect of temperature and pressure.
4. Chemical engineering thermodynamics, chemical reaction equilibrium.

In order to organize a petroleum refining course within the short period of one semester, it is necessary to concentrate on the analysis of the most widely used refining processes and the principles of material balance calculations. There is not enough time for dealing in detailed processes. Topics such as atmospheric and vacuum crude oil distillation, delayed coking, reforming, catalytic cracking, hydrocracking, hydrotreating, alkylation and blending are covered in this course and are listed in detail in the block diagram (see Fig. 2).

Table 3 lists the reading material for the course.

ASSIGNMENTS

Problem solving is a part of chemical engineering. The various rules, principles and their applications, in either designing of equipment, material and energy balance calculations, or the evaluation of performance of a particular process, are usually given to the students as assignments which they can attempt to solve themselves. Since modern engineering practice usually involves groups of engineers, group assignments will provide the students with an opportunity to function effectively as a team member. Most students learn better in a co-operative environment where a significant amount of work is done in groups. Usually the class is divided into several subgroups with two or three students. The assignments are the same for all groups while the values of operating and design parameters are different for each group. A series of regular assignments with regular feedback should help the students in relating theoretical problems to real engineering situations. Moreover, each student is assigned a crude assay and has to work out all the different processing on that crude. This method will make the students responsible for the analysis and problem solving associated with each crude. For example, some crudes have a weight percent of sulfur that should be entered in all material balance calculations while it changes to H_2S through hydrocracking. However, if the crude has some traces of nitrogen and oxygen, different methods of calculations and graphical methods are used. A few assignments are described for reference.

Assignment 1

Develop a true boiling point (TBP) and gravity mid percent curve for your crude oil. Use the curve to calculate the Watson characterization factors for the fractions having mean average boiling points of 550°F and 750°F. Classify the crude.

Assignment 2

From your TBP—gravity curve, make a complete material balance around an atmospheric crude still. Assume a feed rate of 10,000 BPD crude oil to the atmospheric crude still.

General procedure for calculation:

1. From TBP and gravity curves determine percentages and gravities of fractions.
2. Using densities of hydrocarbons and other components in natural gas to convert volumes to weights.
3. Determine weight of 1000^{+} bottoms stream by difference.

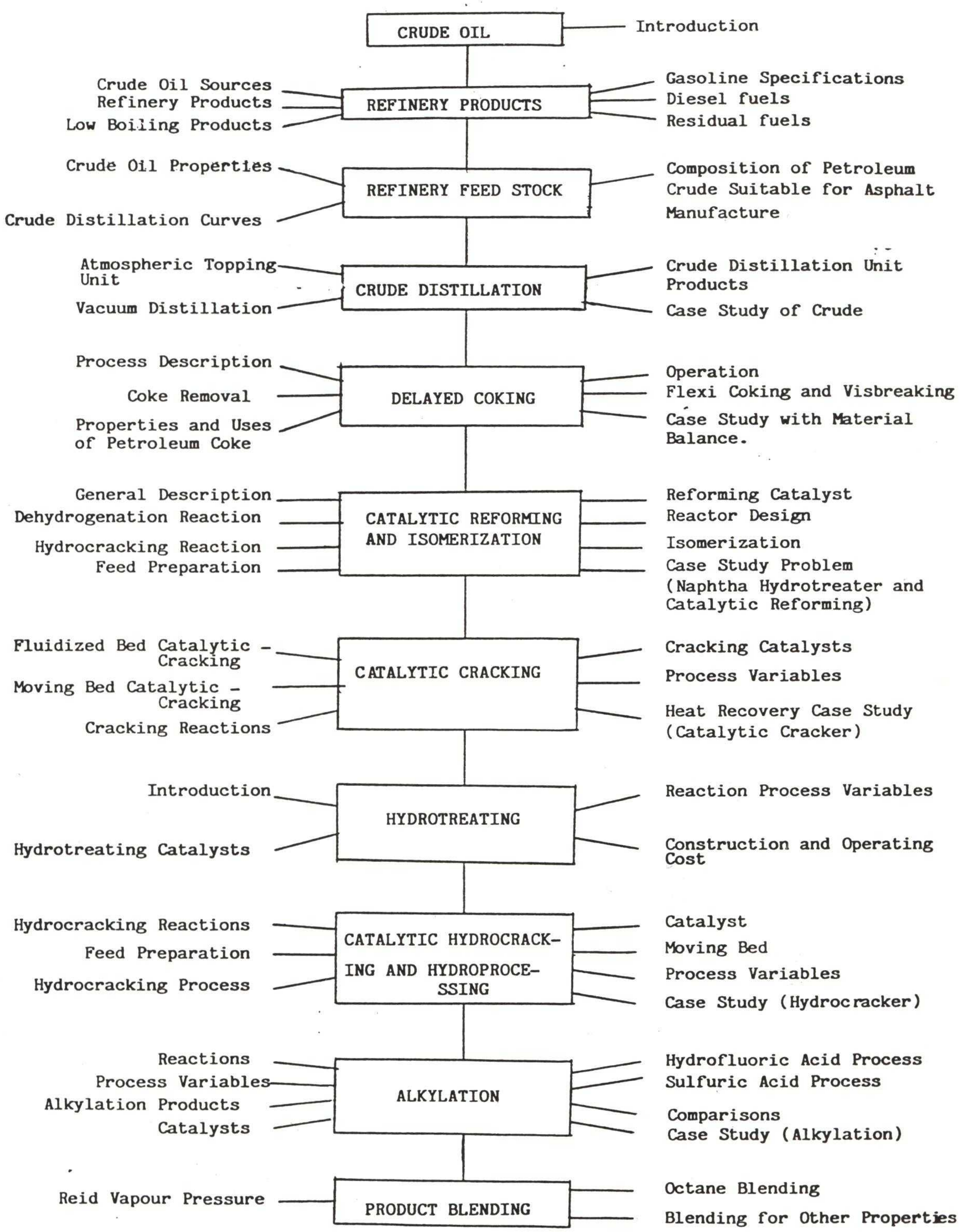

Fig. 2. Topics for the petroleum refining course.

Table 3. Selected reading for the course

Textbooks and papers

1. J. H. Gary and G. E. Handwerk, *Petroleum Refining Technology and Economics*, Marcel Dekker, New York (1975).
2. Ministry of Oil, *Kuwait Oil: Facts and Numbers* (1983).
3. Publication 2140-72, *Liquefied Petroleum Gas Specifications and Test Methods*, Natural Gas Processing Assoc., Tulsa, OK (1972).
4. W. A. Cruse and D. R. Stevens, *Chemical Technology of Petroleum*, 3rd edn, McGraw-Hill, New York (1960).
5. J. B. Waxwell, *Data Book on Hydrocarbons*, Van Nostrand, New York (1950).
6. O. A. Hougen and K. M. Watson, *Chemical Process Principles*, Vol. 1, John Wiley, New York (1943).
7. C. C. Thomas, *Catalytic Processes and Proven Catalysts*, McGraw-Hill, New York (1970).
8. R. J. Hengstebeck, *Petroleum Processing*, McGraw-Hill, New York (1959).
9. R. O. Wickey and D. H. Chittenden, Flash points of blends correlated, *Petro. Refiner.*, **42** (6) (1963).
10. J. G. Speight, *The Chemistry and Technology of Petroleum*, Vol. 3, Marcel Dekker, New York (1980).
11. G. D. Hobson, *Modern Petroleum Technology*, Part 1, John Wiley, New York.
12. D. R. Skinner, *Introduction to Petroleum Production*, Vol. 1, Gulf, TX.

Journals

1. *Journal of Chemical Engineering.*
2. *Oil Gas Journal*
3. *Hydrocarbon Process*
4. *Chemical Engineering Communications Journal*
5. *Industrial and Engineering Chemistry*
6. *Fuel Processing Technology*
7. *Fuel Science and Technology International*
8. *Chemistry and Technology of Fuels and Oils*
9. *Applied Catalysis*

Conferences

1. Symposium on Octane and Cetane Enhancement Processes for Reduced-Emissions Motor Fuels (1992).
2. European Symposium on Computer Aided Process Engineering (1992).
3. AIChE Summer National Meeting, USA.
4. AIChE Symposium Series (1991).
5. *Proc. 53rd GPA Annual Convention*, 25–27 March, Natural Gas Proc. Assoc., Tulsa, OK (1974).

Assignment 3

Calculate the coke yield and make a material balance on a delayed coker including gas balance.

Assignment 4

Make an overall material balance around the reformer for 96 RON (research octane number) clear gasoline blending stock.

Procedure:

1. Calculate the characterization factor of the feed.
2. Determine C_5^+ gasoline volume yields from figures.
3. Determine weight or volume yields of H_2, $C_1 + C_2$, C_3, iC_4, nC_4 from figures.
4. Calculate weight yield of all product streams.
5. Make sulfur and nitrogen balance.

Assignment 5

Using your crude oil cuts 650–800°F and 800–1000°F as a feed to FCC (fluidized-bed catalytic cracking) unit, make an overall weight and volume material balance when operating at a 65% conversion level and a once-through operation with zeolite catalyst. The yields of various product streams are obtained from figures for silica-alumina or zeolite catalyst. The sulfur distribution in the products is also to be estimated from figures.

Assignment 6

Estimate the hydrogen consumption required to remove the sulfur completely from a hydrotreater feed stock and to reduce the nitrogen content of the product to 15 p.p.m. by weight. The 48.5 API naphtha feed to the unit contains 0.62% S, 0.15% N and 0.09% O by weight.

Assignment 7

Make an overall material balance, including a hydrogen balance for your coker and FCC gas oil as a feed to a hydrocracker. The hydrocracking hydrogen consumption is 2000 SCF/bbl of feed.

Procedure

1. Use figure to determine the volume percentage (C_5–180°F) naphtha.
2. Enter the next figure with vol. % (C_5–180°F) and feed K to obtain volume percent (180–400°F) naphtha.
3. Calculate the liquid volume percent butanes formed from:
   vol. % $iC_4 = 0.377$ (vol. % C_5–180)
   vol. % $nC_4 = 0.186$ (vol. % C_5–180)
4. Calculate the weight percent of propane and lighter from:
   wt% $C_3 = 1.0 + 0.09$ (vol. % C_5–180)

Assignment 8

- Calculate the number of barrels of n-butane that have to be added to mixture of 1250 barrels of HSR (heavy straight run) gasoline, 750 barrels of LSR (light straight run) gasoline and 620 barrels of C_5^+ TCC (thermoper catalytic cracker) gasoline to produce a 9.0 p.s.i. Reid vapor pressure. What are the research and motor octane numbers of the blend? What would be the sensitivity if 2.8 g Pb/gal were added in the form of TEL (tetra-ethyl lead) motor gasoline mixture?
- Calculate the amount of butane needed to produce a 12.5 p.s.i. RVP (Reid vapor pressure) for a mixture of 2730 barrels of LSR gasoline, 2490 barrels of 94 RON clear reformate, 6100 barrels of heavy hydrocrackate and 3600 barrels of C_5^+ FCC gasoline. How much TEL must be added to produce a 90 RON product?
- What is the flash point of a mixture containing 2500 barrels of oil with a flash-point of 120°F, 3750 barrels with a flash-point of 35°F and 5000 barrels with a 150°F flash-point?

The solutions of these assignments require thoughtful implementation of energy and material balance calculations, engineering idealization and approximation.

To facilitate learning, drop quizzes are organized based on the previous lectures which mainly include definitions and brief descriptions of the process.

LABORATORY EXPERIMENTS

Laboratories are designed to familiarize students with certain aspects of theoretical and practical fundamentals and introduce them to the atmosphere of industrial operations. In the laboratory, the students will conduct many experiments, such as finding the grade of the intermediate stream or final product from the refinery. In order to undertake quality control in a refinery, students have to get familiarized with modern equipment and tests. The laboratory is equipped with modern equipment such as an automatic distillation tester, an automatic flash-point tester, an automatic kinematics measuring system, an X-ray sulfur meter, and an automatic pour/cloud point tester to analyze the different properties of the petroleum products. The following is a brief summary of the above equipment.

Automatic distillation tester

This is widely used to test the distillation of petroleum products according to ASTM D 86. It performs the test automatically, records temperatures corresponding to percent recovered, calculates loss correction, or barometric correction and prints raw data and corrected results.

Automatic flash-point tester

This is a fully-automated flash-point tester which can measure the flash-points of petroleum products in a temperature range of 40–370°C with a platinum resistance probe.

Automatic kinetic viscosity measuring system

This is a fully automated system for the measurement of the kinetic viscosity of petroleum products. In this system, processes like temperature equilibrating, time counting, sample discharging, viscometer cleaning/drying, etc., are carried out automatically. Kinetic viscosity is calculated with the help of a personal computer.

X-ray sulfur meter

This helps to analyze the sulfur content of crude and petroleum products such as fuel oil, gas oil, kerosene, etc., by non-dispersive X-ray fluorescent spectrometry. The measuring range is 0–5 wt%.

Automatic two-post cloud and pour point CFPP (cold filter plugging point) analyzer

The three most important tests of low temperatures on petroleum products like cloud point, pour point, cold filter plugging point can be performed with this apparatus. This analyzer allows two simultaneous determinations, and each cooling jacket can receive either a cloud or a pour point measuring head. Depending on the selected measuring head, the test is performed in strict accordance with the parameters of the selected standard.

By the end of the course, the students have the opportunity to visit refineries in Kuwait (belonging to the Kuwait National Petroleum Company and the Kuwait Oil Company, etc.). This will enable the students to become familiarized with the equipment, controls and refining processes such as atmospheric and vacuum crude oil distillation, delayed coking, reforming, catalytic cracking, hydrocracking, hydrotreating, alkylation and blending.

CONCLUSION

Since Kuwait's entire economy is based on oil industries the demand for a steady and economical supply of refinery products is constantly increasing. Obviously, there is therefore a demand for professionally qualified men and women to manage and supervise the planning, construction, operation and maintenance of the existing refining plants. The petroleum refining course in chemical engineering at Kuwait University adequately exposes the students to the theory and practice of different refinery processes. It prepares the students to become competent engineers and to be responsible for the different tasks they are entrusted to carry out in the future. Including 'petroleum refining' in the chemical engineering curriculum is an adequate method of giving students the necessary skills. Realizing the need for technical manpower in the development of the country, the Kuwait Government offers financial support to educate students and encourage them to take up research.

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