PRODUCTION OF CLEAN DIESEL OILS*)

A.S. Nasution,E. Jasjfi and Evita H. Legowo

I. INTR UDUCTION

Cars and fuels have been developed simultaneously and nowadays cars demand a very sophisticated fuel indeed. Environmental restriction and efforts to minimize the pollution problem by exhaust gases are causing design changes in cars that in turn are having some effects on fuel quality. The development of processes for making high cetane number gas oil blending components and the widespread use of additives to enhance fuel properties have all contributed to the highly developed motor fuel used today[1].

Gas oil components produced in the refineries generally consist of predominantly straight-run gas oil (SRGO) obtained from the fractional distillation of crude oils. There are two types of straight-run gas oil i.e. a sulfur rich (0.9-1.9 wt.%) aromatic source, and a low-sulfur (<0.2 wt.%) paraffinic crude source[2]. To satisfy the growing demand for diesel fuel, increased use of cracked stocks is anticipated.

The primary requirement in diesel oil properties is that it should burn smoothly, without exploding, under the condition existing in the combustion chamber, so that maximum amount of useful energy is liberated. The ignition quality of a diesel oil is measured by its cetane number, which depends on its hydrocarbon composition. Different refineries produce diesel oil of different compositions, depending on the blending components available.

Hydrocarbon compositions of the gas oil components show marked variation in their precombustion and ignition characteristics and so differ in their combustion behavior in an engine. Such a selective hydrocracking process has the following reaction: desulfurization, denitrogenation, deoxygenation, saturation and isomerization which could improve the flowing properties of gas oil components: sulfur, nitrogen, polycyclic aromatics and total aromatics, product stability, colour, neutralization number and distillation temperature (T50 and T90)[3].

The properties of the straight-run and cracked gas oil components, and improving their quality by a hydrotreating process to meet the clean diesel oil specification and production of gas oil components in Indonesia's refineries are described. A brief deliberation is offered on the impact of the changing diesel oil quality requirement, particularly due to the environmental restriction, on the refinery configuration.

II. PRODUCTION OF DIESEL OIL IN INDONESIA REFINERIES

The normal boiling range for diesel oil is 250 to 370°C. High speed diesel may use oils initial boiling point as low as 140°C. The 50% distillation point should not exceed 300°C.

Diesel oil produced in the refineries generally consists of predominantly straight-run gas oil obtained from the fractional distillation of crude oil; however, compounds such as thermally and catalytically cracked gas oils are sometimes included.

Over 1,063 MBPSD total of crude oils are processed in Indonesia's refineries to produce fuel oil, lube oil and petrochemical feedstock. Diesel oil components consists the following diesel components: straight-run, visbroken, deleyed coker, cat. Cracked, and hydrotreated gas oils. About 30% on this total gas oil components (except hydrocr acked gas oil components is hydrotreated to improve its performance[4,5].

The quality of straight-run diesel oil, such as hydrocarbon types, sulfur or wax content, will in general reflec the nature of crude oil. Sulfur content of straight-run gas oil increases with sulfur content of the crude oil.

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The high sulfur SRGO has good quality (48-54 Cetane Index) but is indeed moderate in polycyclic aromatics (PCA) (>20 vol of PCA). The low-sulfur SRGO has excellent cetane quality (58-62 Cetane index) and low in aromatics (<10 vol.%) but it is much higher in paraffinic of high normal type and having high pour point.

Cracked stocks such as light cycle oil, coker gas oil and visbroken gas oil have much higher polycyclic aromatics (45-60 vol.%) and olefins and much lower Cetane Index (28-35 Cetane Index) than those straight-run gas oils. Typical aromatic distribution of straight-run and light cycle oils is given in Table 1.

Colour problems of the gas oil components are caused by the presence of cracked stocks, high nitrogen content and unsaturated or reactive components.

The majority of crudes contain only small amount of total nitrogen, in the order 0.1 wt.%, or less. With increasing boiling point the nitrogen content also increases, and reaches a maximum in asphaltic distillation residiues. Relation between sulfur content of diesel of components and their feedstocks, and cetane number of various types of diesel oil components and are shown in Tables 2 and 3.

Some upgrading treatment may be needed if the proportion of the low performance of gas oil components such as naphthenic straight-run, thermal and catalytic cracked gas oils in the refinery gas oil/automotive diesel oil pool. Influence of feedstock type of hydrocraking processes on the diesel index of hydrocracked diesel oil products is given in Table 4.

Table 1
Typical aromatics distribusi of straight-run and light cycle gas oil

Aromatic Distribution	Straight-run Gas Oil vol.%	Light Cycle Gas Oil vol.%
Total aromatic	20-35	50-70
Mono aromatic	15-30	5 -15
Di-aromatic	5-25	40-50
aromatic distribution	0-5	5-10
Typical cetane index	>50	>28

Table 2
Relation between sulfur content of diesel oil component and their feedstocks

Diesel Oil Components	Sulfur Contents, wt.%	
	Feedstock	Gas Oil Product
Straight-run diesel oil	1.15	1.05
	2.01	0,90
	3,10	1.45
	3.15	1.85
Thermal-cracked diesel oil	2.35	1.05
	3.35	1.55
Catalytic cracked diesel oil	1.5	0.75
	1.85	1.55

Table 3
Cetane number and specific gravity of diesel oil components

Diesel Oil Components	Specific Gravity 60/60°F	Cetane Number
Straight-run Diesel Oil		
- Paraffinic	0.812	62,0
	0,823	57,0
	0,839	54,0
	0,845	50,5
- Intermedia	0.869	41,0
- Naphthenic	0,889	32,5
Thermal craked diesel oil	0,878	45,0
Catalytic cracked diesel oil	0,847	47,0
	0,851	39,0
	0,872	35,5
Hydrocracked diesel oil	0,823	62,0

The chief requirements for gas oil or diesel fuels are high cetane number, freedom of impurities, and a fairly high flash point. With high stability good diesel fuel. The delay time is short. Requirements for high speed diesel oil are more exacting than that for light diesel oil. Slow speed diesel engines can use a wide variety of oils while high speed engines require limited variation in properties. Current automotive/high speed diesel oil specification in Indonesia is sown in Table 5.

III. IMPACT OF HYDROCARBON COMPOSITION OF THE GAS OIL CHARACTERISTICS AND PERFORMANCE

Diesel oil components can be classified as follows: paraffinic, olefinic and aromatic diesel oil. Different hydrocarbons show marked variation in their precombostion and ignition characteristics and so differ in their combustion behavior in an engine.

A. *Combustion*

In the course of the precombustion and combustion periods both physical and chemical changes occur in the fuel.

The physical changes which take place in the injector itself are responsible for the preparation of fuel in such a manner as to present the largest surface area of the fuel and proper combustion chamber coverage to en sure a high level of air utilization. Fuel characteristics exert only a second-order effect on distribution in the engine cylinder, the influential characteristics being viscosity, surface tension, volatility, and specific gravity.

While these four characteristics are interdependent it is not difficult to see that increased fuel viscosity and surface tension will give rise to increased droplet size and possibly greater penetration of the fuel particles into the combustion chamber. That this is true has been amply demonstrated in engines designed to use distillate fuel and which have changed to high-viscosity residuals. In all cases the resulting over penetration can readily bee seen in the form of circular deposits of carbon on the piston crowns where the liquid fuel has struck the piston and complete combustion has not taken place. Viscosity at 40°C of Indonesia's specifications are 1, 6-5,8 cSt.

Volatility changes alter the vapor/liquid ratio within the cylinder, and increased Volatility will reduce droplet size and penetration. Indonesia's specification on the specific gravity and T_{90} recovery are 0.82-0.87 and 370°C, respectively. On the other hand, increased specific gravity will increase penetration. In so far as the overall effect will be one which influences air utilization, and therefore the combustion process as a whole, it is of considerable importance in these days of public interest in smoke emission from engine exhaust pipes.

The average droplet size in the fuel atomization increases which kinematic viscosity of diesel oil. Among the various hydrocarbon types, paraffins have a lower viscosity, surface tension, volatility and density compared to the aromatics.

Table 4
Feedstock type of hydrocracking proccesses on the diesel index of the influence of hydrocracked diesel oil product

	Type of Feedstock		
	Non-Paraffinic Vaccum Distillate vol. %	Paraffinic Vacuum Distillate vol.%	Paraffinic Wax vol.%
Feedstock conversion	33.66	50.93	50.55
Diesel oil products			
Yields	20.17	31.9	27.89
Diesel index	45.2	74.8	87.3

Table 5
Current Indonesia vs clean diesel oil

		Indonesia	USA	Europa
Cetane Number		45	48	52
Denity,	kg/m^3	820	820-860	837
T90,	°C	370	-	350
Aromatics,	vol. %	-	10	-
Polyaromatics,	vol.%	-	1.4	6
Sulfur,	ppm	5,000	500	50

Table 6
Relative reaction rate of hydrodesulfurization of sulfur compounds

Type of Sulfur components	Mercaptane	Dialkil Sulfide	Thiophene	Benzo thiophene	Dibenzo-thiophene
Relactive relaction rate	28	28	28	7	1

B. *Ignition Quality*

For the purpose of defining ignition quality, the cetane number scale has been adopted, cetane and A-methyl naphthalene being the high and low standards respectively. The ignition quality of the fuel is a measure of the ignition delay of the fuel combustion; fuel of poor ignition quality have long delay time and vice versa[1].

The spontaneous ignition temperature of n-paraffins is much lower than that of aromatics and olefins. Therefore, straight chain hydrocarbons are preferred to branched chain hydrocarbons or aromatics. The influence of aromatic composition (P-paraffinis, N-naphthenes and A-aromatics in wt.%) on the cetane number of the gas oil is given by the following equation[1].

$$CN = 0.85P + 0.1N - 0.2A$$

Stability is also important particularly for long period storage of diesel oil, and this is related to its olefin components which is prone to undergo oxidation/polymerization reactions, forming what is known as gum.

IV. IMPROVEMENT THE DIESEL OIL QUALITY

Changes in fuel quality could offer some alleviation of the smoke emission problem. Specific gravity, viscosity, volatility, ignition quality, aromatic, sulphur and nitrogen contents may be influential factor in determining smoke levels. Future Asia-Pacific and US-diesel specifications are presented in Table 5[6.7].

Reducing the specific gravity and viscosity of diesel oil by hydrotreating process gives a fine atomization of injected fuel which induces a high ability of the fuel to find oxygen in combustion chamber. The surface area of injected fuel increases with low viscosity of gas oil.

Low specific gravity and low aromatic and olefin contents hydrotreated diesel oil gas high cetane number and high stability. Hydrotreating improved cetane number of diesel oil by 3 to 8 numbers. Aromatics saturation of gas oil increases with the operating pressure of hydrotreating process. Gas oil components have the aromatic contents of 10-55 vol.% (Indonesia spec: NR and future spec: 47).

Diesel fuel ignition quality is responsible for controlling the rate of pressure rise within the combustion noise. In modern high-speed diesel engines it is difficult to detect any significant noise effect when using fuels of 50 cetane number and above. On the other hand, there is not doubt that the use of fuels of 45 cetane number or below results in a serious increase in combustion noise.

High octane number fuels, which inherently have short ignition delay periods, will show an advantage under could-star-ting conditions and will allow the engine to fire at lower temperatures that do fuel s of low cetane number. The cetane number effects on the cranking time to first combustion noise.

Ignition quality improvers can assist low-temperature starting, but for this particular purpose aspiration of a material of low self-ignition temperature such as ether is also most effective and can greatly reduce the threshold starting temperature.

Sulphur content of various source of gas oils are ranging from 0.5 to 2.5% by weight. Reaction rate of hydrodesulfurization depends on the structure of organo-sulfur components. Relative Reaction rate of hydrodesulfurization of various organo- sulfur compounds is shown in table 6(8). Reducing the sulphur content of gas oil up to 0,05 wt.% can be achieved by hydro-desulphurization process with high operating pressure about 100 bar bar or higher. Sulphur content of Indonesia diesel oils future specifications are 0,05-1.0 and 0,05 wt.% respectively. The presence of nitrogen compounds in the gas oil product may impart objectionable characteristics such as discoloration or lack stability on storage (formation of gums). Indonesia specification for color is 1-3 while no color limitation will be specified in the future. Nitrogen compounds, unlike the sulphur derivatives, are relatively stable to heat and a higher operating condition of hydrotreating process is needed to remove those nitrogen compounds.

Furthermore, the diesel oil specifications now include a cloud point clause in order to ensure satisfactory low-temperature performance of the fuel. Other changes are in respect of provision of the means of calculating cetane index (ignition quality) and calorific value.

V. REFINERY CONFIGURATION FOR PRODUCTION OF CLEAN DIESEL OIL

Paraffinic straight-run and hydrocracked gas oils have high cetane numbers and low aromatic and sulphur contents. Because of the limited paraffinic crude feedstocks and the additional processes of the hydrocracking process for feed preparation (vacuum unit, deasphalted unit and hydrogen plant), this high gas oil performance would be also be produced by the catalytic cracking of reduced crude oil following by the hydrotreating process.

An advantage of this catalytic cracking compared to the thermal cracking (visbreaker and coker) process is an advantage to produce a high octane parameter (high research octane number, low sensitivity and good octane distribution) of catalytic cracked gasoline blending component for reformulated gasoline production⁽⁹⁾.

About 50% by volume of total gas oil components has been treated by hydrotreating process to improve the gas oil performance to follow the Indonesian specification (cetane number > 45 and sulphur content 0.05-1.0 wt.%). For the more stringent future Asia-Pacific specification in the years 2000's, about 90% by volume of these total gas oil component (without hydrocracked gas oil) must improved by hydrotreating processes to get a suitable specification (total aromatic content of 10-20 vol.%, polyaromatic content of <1.4 vol.%, and sulpur content of <0.05wt.%).

With increasing cracked stock portion in the diesel oil pool and the stringent diesel oil specifications (i,e. sulphur content 0,05 wt.%; total aromatics from 10 to 20 vol.% with polycyclic aromatics d"1.4 wt.% and cetane number e"48), the deep gas oil hydrotreating process will play a more important role. Catalyst activity is reduced by the presence of ammonia and hydrogen sulfide in the cracked feedstock. Therefore, for most cracked diesel stocks, it is necessary to reduce sulphur and nitrogen levels in the feedstock before introducing the feedstock to saturation catalyst zone. The traditional hydrotreating process is still dependent on a single-stage reactor system that combines severe operating with hy-

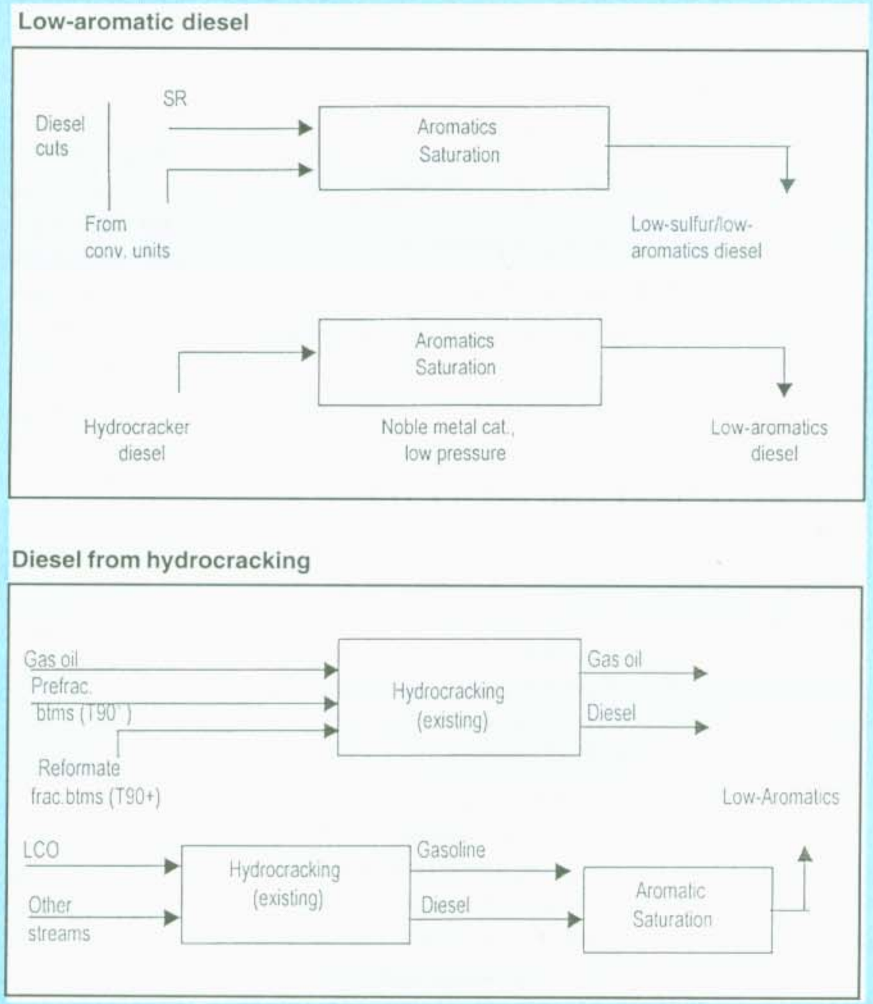

Figure 1
Technology for production of clean diesel oil

drogenation using a single catalyst type such as Co-Mo/Al_2O_3. Other process is a dual-stage reactor in which the hydrodesulphurizing step with Co-Mo/Al_2O_3 catalyst is followed by hydrocarbon saturation step using Ni-Mo/Al_2O_3or Ni-W/Al_2O_3 catalyst (10.11). The pressure of this dual-stage system is much lower at around 50 kg/cm^2 as compared to above 80 kg/cm^2 for the single-stage system[39]. Technology for production of clean diesel oil is given is Figure 1.

VI. CONCLUSION

Hydrocarbon composition of gas oil components plays an important role on the combustion performance of motor fuel, such as cetane number, fuel atomization in pre-combustion and stability.

The more stringent specification gas oil or diesel oil in Asia-Pacific in the years 2000's to reduce pollution from motor vehicles exhaust gases will press ASEAN refineries to modify their processing configuration. Greater role and capacity will need to be given to catalytic processes, such as catalytic cracking process, hydrocracking prosess and deep hydrodesulfurication process.

Although cetane number is the overriding factor in determining fuel combustion performance, other laboratory test such as stability, color and viscosity must also be anticipated in the future.

As catalytic processes become more important in preparing gas oil blending components in the future, it is advisable that supporting laboratories be provided with catalyst testing facilities and that cooperation in catalyst performance test and development be initiated.

REFERENCES

1. Weismann, J., Carburants et Combustibles pour Moteurs a Combustion Inteme", Edition Tecnip, Paris, 1970, pp. 157-480.
2. John Dosher R., Jack Carney T., Sulfur Incereases Seen Mostly I Heavy Fraction of Lowe Quality Crudes, Oil and Gas Journal, May 23, 1994, pp. 43-48.
3. Nasution A.S., and Abdul Gafar, "Hydrodesulfurization on Gas Oils using Co-Mo Al_20_3 catalyst, 3rdAnnual Asia-pacific coference,1977.
4. Nasution A.S., and Abdul gafar, "Survey on Catalyst Use in ASEAN Refineris", 2nd ASCPE Refining Worskhop, Bandar Seri Begawan, Brunei Darussalam, 1993
5. Nasution A.S., and Jasjfi, E., Hydrotreating processes in ASEAN Refineries, 4th Refining Workshop, Bangkok, Thailand, 1995.
6. News, New Diesel litmus Test for California Refineries R5egulation, Oil and Gas Journal, August 30, 1993,pp. 21-26.
7. Special Report, Fuel Quality Standards For Year 2000 Proposed by the European Commission, Fuel and Lubes international, December 1996, vol. 2, No. 12, pp. 10-11.
8. Germain, J.E., Catalytic Conversion of Hydrocarbons, Academic Press, New York,1969.
9. Le Page, J.H., Aplied Heterogenous Catalyst, Edetion Technip, Paris, 1987.
10. Cooper, B.M. et al, Hydrotreating Catalyst For Diesel Aromatics Saturation, Hydrocarbon Procssing, June 1973, pp. 53-87
11. Thomas, C.L, Catalytic Processes and Proven Catalyst, Academic Press, New York, 1970. •

In preparation of the study, x core plugs are drilled. Determination of basic parameter and identification of core plug sample are carried out following the API – RP 40. For example, the tests of physical properties, i.e. grain density (gr/cc), weight, grain volume (cc), pore volume (cc), porosity (%), and air permeability (Ka, mD).

C. *Measurement of interfacial tension and phase behaviour test*

Spinning drop interfacial tensiometer is the equipment used for determining interfacial tension between liquids – it has the capability to measure interfacial tension as low as 10^{-4} dyne/cm – following:

$$IFT = \frac{(10^6 \pi^2 \Delta \rho d^3)}{(8 n^3 P^2)}$$

where

IFT : interfacial tension, dyne/cm

$\Delta\rho$: difference of fluid density, gr/cm

d : dropping width, cm

n : bias index

P : period, msec.

D. *Phase behaviour test*

Effectiveness of surfactant that is usable in enhanced oil recovery is not only determined by interfacial tension factor but is also influenced by phase behaviour and adsorption of surfactant concentration in pore media/core. To study the type of phase behaviour formed when oil, surfactant, and formation water are mixed, it is necessary to test:

a. Phase behaviour of oil - surfactant - formation water blend

b. Phase behaviour of oil - surfactant - cosurfactant - formation water blend

E. *Adsorption*

Effectiveness of surfactant to reduce interfacial tension and to improve oil recovery is affected by adsorption of surfactant in pore media. In this study, surfactant with x % concentration is dissolved into formation water. The surfactant solution was then placed into a beaker glass that contains a bit of crushed core. After 9 hours immersion, concentration of surfactant in the solution was determined by using ultra violet spectrophotometer. The difference of initial surfactant concentration (x %) and a certain concentration of surfactant in the solution (y %) is the concentration of surfactant adsorbed by pore media (z %).

IV. PROCESS OF SURFACTANT FLOODING LABORATORY TEST

The stage of surfactant flooding laboratory tests process to improve oil recovery is schematically described in Figure – 4.1 below:

a. Formation water saturation

Formation water (F_w) is injected into core plug up to water saturation of 100 %.

b. Determination of connate water saturation (Swc).

Oil is injected into the fully water saturated core plug so that the core is partially saturated by oil. From this stage, connate water saturation data is obtained.

c. Determination of oil recovery factor by formation water injection

By injection of formation water into core, some of oil existing in the core is displaced and is produced. Recoverable oil is recorded. The remaining amount of oil in the core is the residual oil saturation (S_{or}).

d. After water flooding, the surfactant flooding takes place. Recoverable oil is recorded.

In this main step, surfactant solution at the certain concentration is injected into core plug letting the surfactant solution contacts formation water within the plug. Since surfactant has a function of reducing oil-water interfacial tension, the residual oil that is trapped in the pore media can be displaced by the surfactant solution and be produced. Fluid that comes out from core, is a mixture of oil, surfactant, and formation water. Sampling is carried out for five analyzed samples: S1 (0.5 PV), S2 (0.5 PV), S3 (1 PV), S4 (1.5 PV), and S5 (2.0 PV). Due to the nature of the phase, it is very difficult to measure the volume of the recovered oil visually. As stated before, the surfactant tends to be dissolved by oil and mixed within it. To obtain the real oil volumes, infra red spectrophotometer (IR) is used.

Mixture:
Oil – surfactant – formation water.
It is very difficult to measure oil content visually because surfactant is dissolved in oil and is mixed with oil.

e. Calculation of oil recovery factor after surfactant flooding.

V. STANDARD OPERATIONAL PROCEDURE

It is very important to prepare laboratory standard operational procedure for the seven main points that will be tested. Each stage in implementation of surfactant injection laboratory test to improve oil recovery should fulfill laboratory standard operational procedure, such as American Petroleum Institute (API), and Petroleum Production Handbook, supported by ISO 17025. Application of laboratory standard operational procedure for the required laboratory test (see Section III) will en-

Table - 5.1
Laboratory standard operational procedure for surfactant injection laboratory test

No.	Types of analysis	Analysis / method	Equipment	Standard
1	Determination of chemical compositions and physical formation water properties.	- Chemical composition	Water analysis laboratory	API - RP 45
		- Water spesific gravity	Spesific gravity tool	API - RP 45
2	Measurement of physical core properties.	- Porosity	Helium Gas expansion porosimeter	API recommended practise no. 40, supported by ISO 17025
		- Permeability	Digital gas permeameter	API recommended practise no. 40, supported by ISO 17025
3	Fluid (oil and surfactant) physical properties	- Density and - Viscosity	Densitometer Viscosimeter	API - RP 45 API - RP 45
4	Measurement of interfacial tension	- Interfacial tension	Spinning Drop Interfacial Tensiometer	Spinning Drop Interfacial Tensiometer Manual Book and Interfacial Tension Phenomena in Enhanced Oil Recovery Book.
5	Phase behaviour test	- Phase behaviour test	Test tube	Theory of Microemulsion book
6	Water flooding	- to determine oil recovery factor by water injection	Water flooding equipment	Petroleum Production Handbook, Vol. II, by Thomas C Frick.
7	Surfactant flooding	- to determine oil recovery factor by surfactant injection	Surfactant flooding equipment	Petroleum Production Handbook, Vol. II, by Thomas C Frick, and EOR Reprint Series No. 23

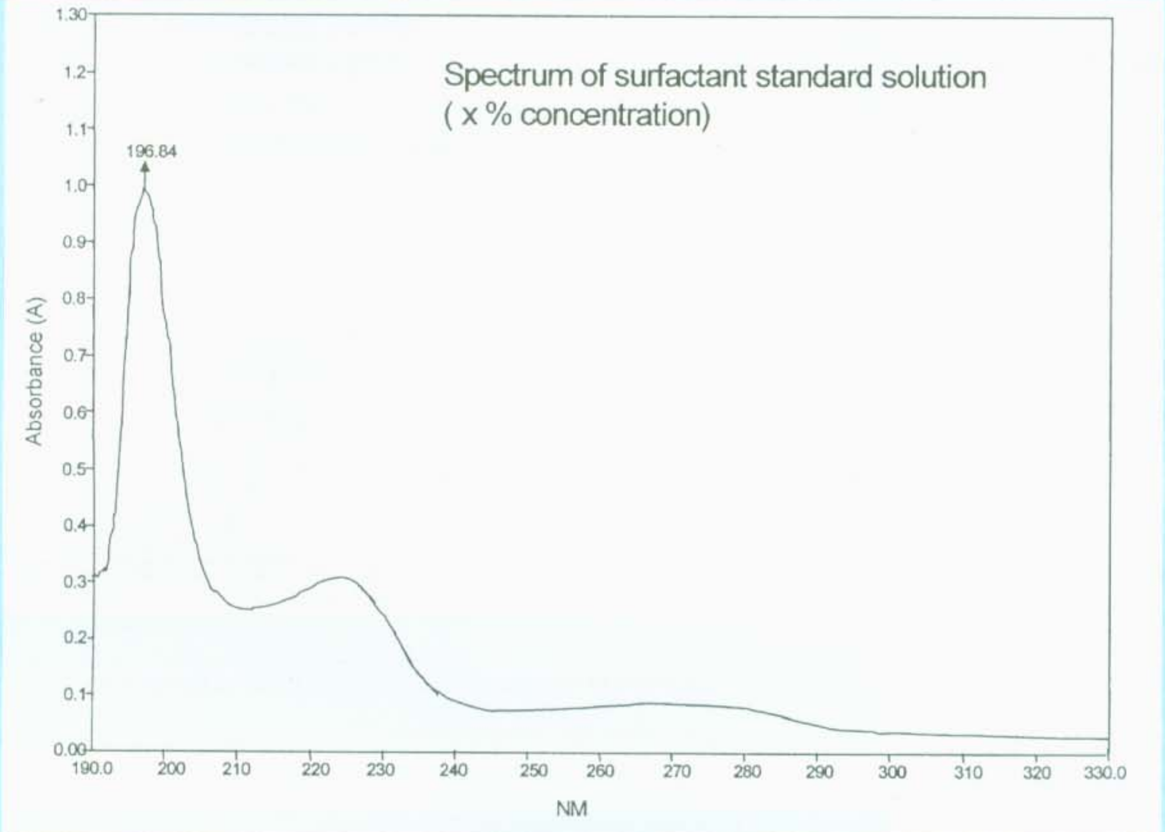

Figure – 6.1
Spectrum of surfactant standard solution (x % concentration)

sure that the obtained analysis result will be accurate. Table - 5.1 shows the standard operational procedure, that contains the seven types of analysis, equipment, method and the used standard for surfactant injection laboratory test.

VI. LABORATORY TEST RESULTS

This section describes the obtained result of the seven analyzed main points (mentioned in Section III) sistematically. The obtained results of the seven analyzed main points are as follow :

1. Formation water analysis.
2. Determination of physical fluid and rock properties.
3. Measurement of interfacialtension.
4. Phase behaviour test.
5. Adsorption test (see Figure – 6.1 and Figure - 6.2)

As mentioned in Section – 3.5 enhanced oil recovery by using surfactant injection method is affected strongly by adsorption of surfactant factor in pore media. Figure – 6.1 indicates the spectrum of surfactant standard solution (x % concentration), whereas the spectrum of surfactant solution after 9 hours immersion is presented in Figure – 6.2. The difference between the two concentrations produces a concentration of y % surfactant adsorbed by pore media. After doing water flooding process, it is followed by surfactant adsorbed by pore media. After doing water flooding process, it is followed by surfactant injection into media pore (core). How tremendous influence of surfactant injection on oil recovery factor in pore media (core) can be seen in Figure – 6.3 . This figure is as an example of enhanced oil recovery laboratory test result by using surfactant injection method.

VII. CONCLUSIONS

1. Surfactant flooding is a tertiary recovery method in which surfactant solution with certain concentration is injected into a reservoir oil to a producing well after the reservoir has approached its economic productive limit by secondary recovery (water injection) method.
2. To obtain accurate data, optimum and reliable results, it is very important and valuable to carry out a sequence of stages from initial until final stages of data preparation for surfactant injection laboratory test, including:

- Formation water analysis.
- Determination of physical fluid and rock properties.
- Measurement of interfacial tension.
- Phase behaviour test.
- Adsorption of surfactant in pore media.
- Water flooding.
- Surfactant flooding.

3. Seven types of work descriptions (mentioned in Section – 7.2) are completed by laboratory standard operational procedure and even supported by ISO 17025.

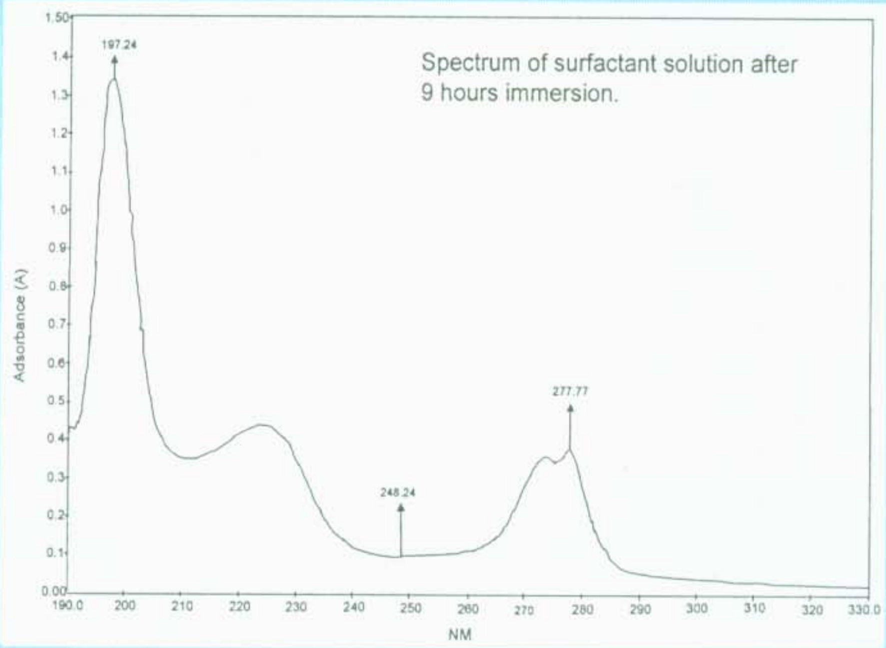

Figure – 6.2
Spectrum of surfactant solution after 9 hours immersion

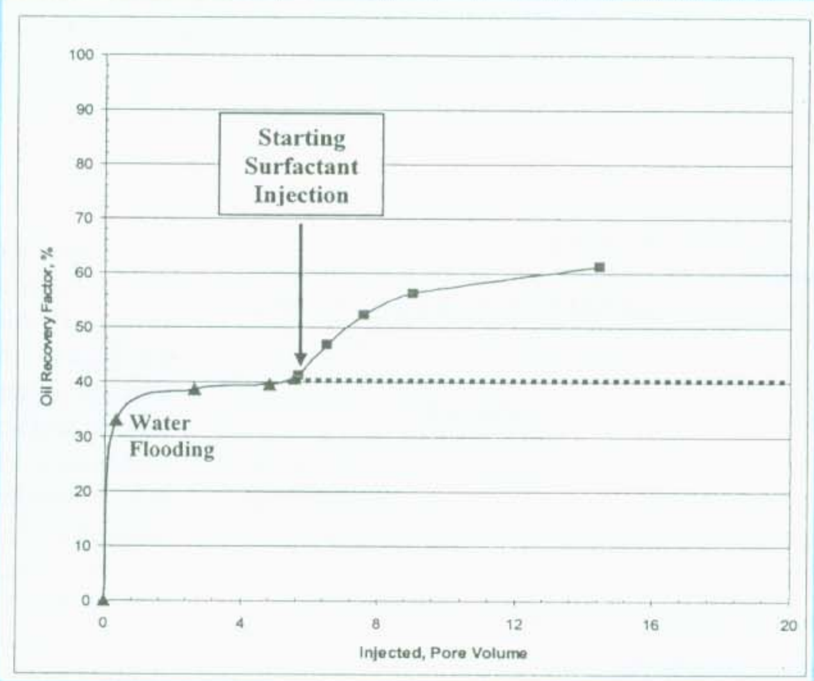

Figure - 6.3
Influence of surfactant injection on enhanced oil recovery

REFERENCES

1. Amyx, J.W, Bass, D.M.Jr., and Whiting, R.L: "Petroleum Reservoir Engineering", McGraw-Hill Book Co.Inc., New York City, 1960.
2. Buckley, S.E and Leverett, M.C.: "Mechanism of Fluid Displacement in Sands", Trans, AIME 146, p. 107-116, 1942.
3. Spencer O.F: "Secondary Recovery Of Oil" The Pennsylvania State University, Pennsylvania, USA, p. 22 – 75, 1959.
4. American Petroleum Institute, API – RP 45.
5. Charles, R.S.: "Secondary Oil Recovery", Lition Educational Publishing, INC. Florida, p.183 – 224, 1966. •