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**BITUMEN:  
NIGERIA'S OTHER BLACK GOLD?**

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BY

A.S. ADEDIMILA

U. L. ARCHIVES



UNIVERSITY OF LAGOS PRESS - 2000  
INAUGURAL LECTURE SERIES

U. L. ARCHIVES

0002, 2000, U.S.A.

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2000

Printed by University of Lagos Press

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ISSN 1119 - 4456

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# 1. INTRODUCTION

## 1.1 Preamble

It would appear that we are at the threshold of Nigeria's second economic breakthrough.

**Black Gold?** The Petroleum industry has become the mainstay of the overall economy of Nigeria, accounting for about 90 per cent of the country's foreign exchange earnings, about 20 per cent of the Gross Domestic Product, and about 85 per cent of the Federal Government collectable revenue. As indicated in Fig. 1 (on page 4), almost all the crude oil produced in Nigeria between 1965 and 1985 was exported (NNPC, 1985). Therefore, in order to ensure continuity and orderly development of the industry, the Federal Government put in place a Petroleum Policy. Prominent among the objectives of the Policy is the development of the large deposit of tar sands in the country.

The extensive geological studies carried out largely by the staff of the University of Ife (now Obafemi Awolowo University) Ile Ife, confirmed the existence of the natural bitumen in Western Nigeria in commercial quantities. Similarly, the limited engineering studies of the naturally occurring bitumen in the Okitipupa area of Ondo State, obtained mainly through research I conducted at the University of Lagos confirmed its suitability for road construction.

Also, reference to various reports, newspaper publications and other information media in Nigeria within the last two decades is a pointer to the fact that petroleum crude, generally a major source of bitumen, has been aptly described as Nigeria's "black gold". Can this "black gold" concept of petroleum crude oil be extended to bitumen? Perhaps the second phase of Nigeria's economic breakthrough is round the corner!

It is in the light of the foregoing that the title of this inaugural lecture has been chosen to read: "Bitumen: Nigeria's Other Black Gold?" to

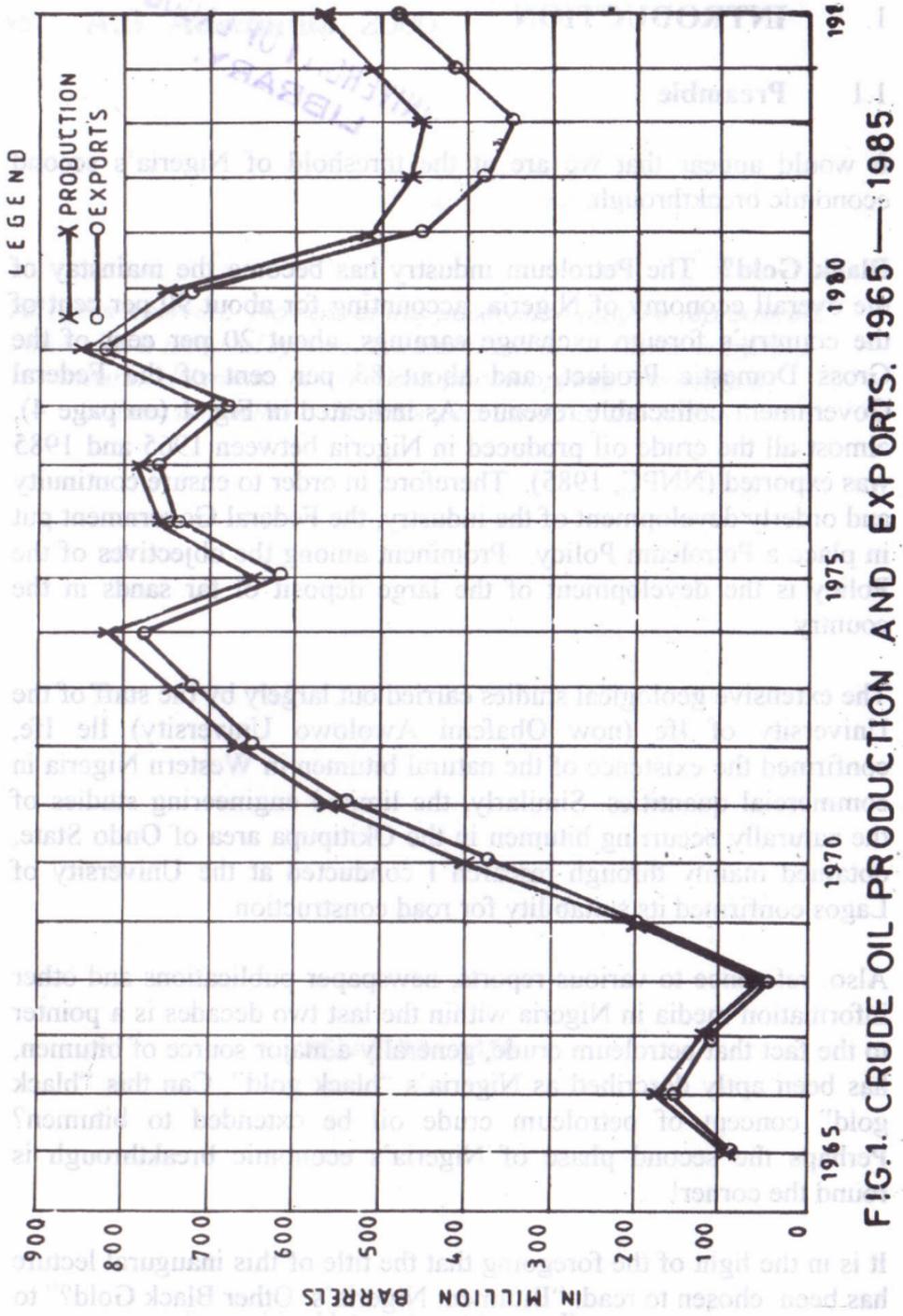


FIG.1. CRUDE OIL PRODUCTION AND EXPORTS, 1965 — 1985

Fig.1 Crude oil production and exports, 1965 – 1985

find out if the natural bitumen can play comparable roles as petroleum crude in Nigeria's economic sector.

## 1.2 Definitions

Three terms that have been used interchangeably by both the 'uninitiated' as well as some asphalt technologists, and of course, with attendant confusion therefrom are ASPHALT, BITUMEN and TAR. While there are striking similarities, there are also obvious differences, particularly between asphalt and tar. Thus, to understand what bitumen, asphalt and tar are, some technical definitions will first be considered so that an orderly description of the materials can be evolved.

**Bitumen:** According to the American Society for Testing and Materials (ASTM), "bitumen is a mixture of hydrocarbons of natural or pyrogenous origin, or combinations of both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid or solid, and which are completely soluble in carbon disulphide ( $CS_2$ )". It is significant to note the aspect of definition which indicates complete solubility in carbon disulphide. Thus, pure or impure bitumen can be assessed by its degree of solubility in  $CS_2$ . By the same American concept, there are two types of bitumen (or bituminous materials) - Asphalt and Tar.

**Asphalt:** Similarly, according to ASTM, "asphalt is a black to dark brown solid or semi-solid cementitious material, which gradually liquefies when heated, in which the predominating constituents are bitumen, all of which occur in the solid or semi-solid form in nature or are obtained by refining petroleum or which are combinations of the bitumen mentioned with each other or with petroleum or derivatives thereof". The various sources and types of asphalt in present day use will be discussed later in this lecture. However, it is pertinent to mention here that there are two major sources of asphalt - those occurring naturally such as the Ondo State "Tar Sands" and those obtained by the refining of petroleum such as those produced at the Kaduna Refinery in Nigeria.

Asphalt is also described as the product of fractional distillation of

petroleum. This distillation process can be over a short period of time as in the refinery (e.g., Kaduna Refinery) or over longer periods of time as in nature (e.g., Ondo State "Tar Sands").

**Tar:** Unlike asphalt, tars are products of the destructive (rather than fractional) distillation of a number of organic materials - coal, wood and sugar. Tar is similarly produced from petroleum by chemical (rather than physical) change - that is, destructive distillation of petroleum. Since tars are the product of chemical change, they do not occur in nature.

Tar has an important historical significance - it was the first material used for road surfacing in Nigeria. Even today, roads constructed of asphalt or bitumen surfaces are still referred to in Nigeria as "tarred" roads.

### 1.3 Comparison: Bitumen/Asphalt versus Tar

From the above definitions and with due reference to existing literature, it is clear that bitumen is quite similar to asphalt while tar differs significantly from asphalt and bitumen. Therefore, during the course of this lecture, asphalt and bitumen will be used interchangeably as this, to a large extent, can be regarded as a question of semantics.

At this juncture, some of the differences between asphalt (or bitumen) and tar, according to Monismith (1961), will be highlighted.

**Manufacturing** - Asphalt is a product of fractional distillation which does not involve chemical reaction while tar is a product of destructive distillation with chemical changes. Thus, unlike asphalt, tar does not occur in nature.

**Chemical** - Tar contains more free carbon which is insoluble in carbon disulphide and therefore more brittle at low temperatures.

**Performance: Oxidation** Asphalt is highly susceptible to oxidation (hardens) while tar has some resistance to oxidation and it is therefore used for roofing as it does not harden unnecessarily with resultant cracks.

**Temperature Susceptibility** - Tar is more susceptible to temperature, hence it is less used in roadways as it softens during hot weather and becomes hard and brittle under cold weather.

**Water Resistance** - Tar is more resistant to the disintegrating action of water and it is therefore more used for water-proofing purposes.

**Dust Resistance** - Asphalt is less resistant to dust. Tar will wet and coat mineral aggregate, when damp or dusty than asphalt.

**Overheating** - Some grades of asphalt and tar require heat treatment before usage. Tar may be overheated and spoilt more easily than asphalt.

**Solvent Action** - Tar is less susceptible to the dissolving action of petroleum solvents or distillates. It therefore performs better in parking areas.

#### 1.4 Historical Perspective

Asphalt is surely not a product of modern civilisation. Before the invention of the wheel some ten thousand years ago, there were individual and mass movements of people and goods. From recorded history, the most advanced ancient highway system was built by the Romans covering Europe, North Africa and part of Asia Minor. However, one is not certain of the extent of the use of asphalt in the construction of these early roads.

The first recorded use of asphalt, according to Professor Carl L. Monismith of the United States of America, dates back to 3800 BC in Mesopotamia where the material was used as an adhesive mortar for building stones and paving blocks. During this period, reservoirs, canals and bathing pools were constructed with these blocks which

were made watertight using asphalt found in natural deposits in the region.

A magnificent road was reportedly constructed to aid the building of the Great Pyramid in Egypt around 3000 BC. The streets of Babylon city were also reportedly paved as early as 2000 BC. The Holy Bible also records that, to save Moses from death as then decreed by the Egyptian King Pharaoh for all new born Hebrew male children, his mother obtained a basket and coated it with bitumen to make it watertight before placing the basket with Moses inside it on the river (Exodus 2:3, Revised Standard Version).

Similarly around 300 BC, asphalt was used in Egypt for mummification and early in the 19th century (1802) asphalt was used in paving in France utilising natural deposits of rock asphalt from the Rhone Valley. In 1838, rock asphalt was used for sidewalk construction in Philadelphia. Also in 1876, portions of Pennsylvania Avenue in Washington, D.C. were paved using either Trinidad Lake asphalt or asphalt from Venezuela. Today, asphalt is used all over the world for various purposes as will be highlighted later in this lecture.

In Nigeria, there are no significant records to indicate the first use of asphalt for road construction or other purposes. However, according to Engr. Olugbekan of the Federal Ministry of Works and Housing (Olugbekan, 1995) the first inter township bituminous surfacing was constructed in 1926 on a section of the Lagos-Abeokuta road which was within the then Colony Province. Unfortunately though, there are no indications as to when and where township roads were first surfaced with bituminous materials in Nigeria. The bituminous binder then used must have been tar and the construction process under the then Colonial Administration was by direct labour, using the staff of the then Public Works Department (P. W. D.).

As at June 1995, Federal Roads in Nigeria comprised 53,650 km of asphalt concrete and 7,712 km of surface dressing (F.M.W.&H., 1995).

## 2. USES OF ASPHALT

Asphalt is an extremely versatile material and its usage, which can be likened to that of the palm tree, is widespread.

The major uses, specified by the British Standards Institution (B.S.I.), the American Association of State Highway and Transportation Officials (A.A.S.H.T.O.), ASTM and other Agencies worldwide, can be categorised as follows:

### 2.1 Paving and Road Building

By far, the greatest use of asphalt is in paving and road building, particularly flexible pavements. These include asphalt concrete, surface dressing and seal coats, prime and tack coats, and in soil stabilisation. Examples of such areas of usage are in

- (a) Highways, streets and driveways
- (b) Airfields
- (c) Parking areas, service (petrol) stations and industrial floors
- (d) Tennis courts and playgrounds such as basketball floors

In addition to the construction of new pavements, asphalt is also used for major rehabilitation of old pavements as well as routine maintenance of deteriorating pavement surfaces:

### 2.2 Protective Coating and Hydraulic Structures

This includes the use of asphalt where a protective or an impervious coating of surface is required. Materials used are generally highly blown asphalt, that is, air blown or catalytically blown asphalt in which asphalt are blown in the presence of special catalysts such as phosphorus pentaoxide ( $P_2O_5$ ). Asphalt used can also contain finely divided mineral fillers as in the case of filled asphalt. Examples of such areas of usage are in

- (a) Riverbank revetments - for slope protection
- (b) Reservoir lining

- (c) Canal lining
- (d) Swimming pools
- (e) Dam facing
- (f) Pipeline coating -asphalt coated pipes will protect against undersea corrosion

### 2.3 Roofing

Asphalt can be used for the roofing of all kinds of buildings, from individual homes to factory buildings. In the United States of America, about 85 per cent of roofing are of asphalt, mostly asphalt shingles (Monismith, 1961). Asphalt used for roofing are usually produced by the air-blowing process and the materials produced are generally semi-solid at ordinary temperatures. The higher the amount of air-blowing, the higher the softening point of the air-blown asphalt. While relatively low softening point asphalt can be used for flat roofs, steep pitched roofs require higher softening points and therefore considerably more air-blowing is performed on the base asphalt material. Examples of such areas of uses are in:

- (a) **Prepared Roofing** – products are already manufactured and packaged ready to be applied to the roof deck, usually by nailing only, as in the case of aluminium roofing sheets. Prepared roofing includes:
  - (i) Asphalt Shingles - it is weather-proof and fire resistant and composed of three basic materials - asphalt, felt and mineral granules such as aggregate or slag. In the preparation, felt is saturated on both sides with asphalt, and both sides covered with harder and tougher coat of asphalt in which mineral aggregates are embedded. The material is then cut into individual shingles or strips. Asphalt shingles are applied to steep roofs of homes, barns and similar structures. They usually fill the need for attractive, efficient and fire-resistant but low-cost roofing for residential construction.
  - (ii) Asphalt Roll Roofing (smooth surfaced) - this consists of smooth

surfaced single layer of roofing felt saturated with asphalt and coated on both sides with harder asphalt.

- (iii) Asphalt Roll Roofing (mineral surfaced) - this consists of smooth surfaced roofing in which mineral granules have been embedded on either one or both sides
- (b) **Asphalt Built-Up Roofing** - this is usually used for flat or nearly flat roofs of industrial or public buildings. It is composed of several layers of asphalt-saturated felt applied to the roof deck. Asphalt is applied between the felt layers for adhesion. Over the top layer a flood coat of asphalt is added and this is covered with gravel or slag. The roof is prepared *in-situ*.

In Nigeria, asphalt is used for roofs of some industrial buildings. It is also used as water-proofing material for the uppermost concrete slabs of unroofed buildings.

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#### 2.4 Other Uses

In addition to the above, asphalt can also be used for the following purposes:

- (a) Automobile brake lining
- (b) Undercoating of automobiles
- (c) Tyre manufacture
- (d) Joint filling and sealing, especially concrete pavements and bridge decks
- (e) Insulating and soundproofing
- (f) Tunnel grouting
- (g) Battery cases
- (h) Polymer and petro-chemical industries for the production of resins, plastics and fibres
- (i) Tree surgery, etc.

In the United States, approximately 75 per cent of the total sales of petroleum asphalt and road oils (soft asphalt) to domestic consumers is for paving, about 16 per cent for roofing and 9 per cent for

miscellaneous purposes. It is also worthy of note that about 92 per cent of the total length of paved rural roads in the United States make use of asphalt (Monismith, 1961).

In Nigeria, efforts made in obtaining similar statistics has not been particularly successful. However, it is not unlikely that up to 90 per cent of bitumen produced in Nigeria is used for paving, particularly in road construction.

### 3. BASIC FORMS OF ASPHALT

As earlier stated, asphalt is the product of fractional distillation of petroleum. When this process of fractional distillation occurs over a long period of time in nature, it results in deposits of materials known as natural asphalt. When the process occurs over a short period of time as in the refinery, it results in manufactured asphalt. Today, the refinery is the primary source of asphalt worldwide, and so far, the only source in Nigeria.

#### 3.1 Natural Asphalt

Natural or native asphalt exists either in a relatively pure form, mixed with an appreciable proportion of mineral matter, in impregnated rock deposits or in large lakes made up of asphalt or a combination of water and asphalt. The estimated reserves for major deposits worldwide are indicated in Table 1 (Adegoke, 1980).

TABLE 1: ESTIMATED RESERVES FOR MAJOR BITUMEN DEPOSITS IN THE WORLD.

Country	Bitumen Deposit	Estimate Reserves(Metric Tons)
Canada	North Alberta Deposits	$388 \times 10^8$
Malagasy Republic	Bemolangu Deposits	$246 \times 10^6$
Nigeria	South Western Nigeria Tar Sand Deposits	$270 \times 10^6$ (minimum)
United States of America	Utah, Kentucky and California Deposits	$351 \times 10^6$ (minimum) $773 \times 10^6$ (maximum)
Venezuela	Orinoco-Guarico Deposits	$281 \times 10^8$

Source : Adegoke (1980)

Although the greater proportion of bituminous materials used for highway and airport pavement construction worldwide is from manufactured asphalt, increasing attention is being paid to natural asphalt deposits. This is because some natural bitumen are known to possess considerably better construction engineering properties as they tend to adhere better to the surface of mineral aggregates in asphaltic concrete because of their composition and in particular, higher content of oxygen and asphaltogenic acids such as those in Trinidad Lake Asphalt (U.N. Institute for Training and Research, 1982 and Shestoperov, 1983).

It has to be noted, however, that not all naturally occurring bitumen meet the requirements for use in road construction. To ensure that roads give long-lasting, satisfactory performance, standards and specifications on characteristics and performance that must be satisfied by construction materials have been developed by such organisations as the ASTM (1978). Consequently, there is a need to ascertain the quality of the naturally occurring bitumen *vis-à-vis* the requirements of such organisations prior to utilisation for road and other construction purposes.

It is also worth noting that while serious efforts are being made for the continuous evaluation and exploitation of the naturally occurring bitumen deposits of other countries such as the United States of America and Canada, it appears Nigeria, until recently, paid relatively little attention to her vast deposits and continued to expend millions of dollars of her limited foreign exchange to import raw materials in the form of asphalt yielding crude petroleum mostly from Venezuela for the manufacture of bitumen at the Kaduna Petroleum Refinery for pavement and other construction purposes. This is because Nigerian crudes are generally not "asphalt-base" crudes.

Based on this background therefore, there arises a need to focus greater attention on the naturally occurring bitumen deposits of Nigeria more so as eventual utilisation of the materials can be expected to have a significant pay-off potential on cost reduction and

foreign exchange preservation on the long run.

While the naturally occurring bitumen in Nigeria will be described in greater detail later in this lecture, a brief description of some other major deposits elsewhere will now be presented.

**Trinidad Lake Asphalt:** According to Monismith (1961), this exists in the form of a lake in Trinidad Island and has been used successfully in roadworks. Although it exists in a lake form, it is relatively hard and can support heavy weights on the surface of the lake. It exists in the lake as an emulsion (emulsified form), containing approximately 40 per cent asphalt, 30 per cent water and 30 per cent emulsifying agent which keeps the asphalt in suspension. Such emulsifiers are mineral matter such as clay. The process of extraction of pure bitumen from the natural asphalt is well described in the literature.

**Gilsonite.** This occurs in Utah and Colorado in the United States and is practically pure natural asphalt as it is more than 90 per cent soluble in carbon disulphide. Gilsonite is generally very hard with a penetration of zero. The mineral is used in asphalt paints, battery boxes and asphalt floor tile, rather than in road construction.

**Rock Asphalt.** In the case of rock asphalt, small quantities of asphalt are found impregnated in rock, usually sandstone or limestone. A good example of this is the Kentucky rock asphalt and has been used extensively for road construction in Kentucky and Indiana States in the United States of America. The material is quarried like other rock deposits, crushed and laid using conventional paving equipment. Although the material is reported having excellent anti-skid surface, it is equally said to be expensive, which has limited its use in road construction. Asphalt is also found impregnated in sands such as those in Alberta, Canada and Okitipupa area of Ondo State, Nigeria (tar sands).

### 3.2 Manufactured Asphalt (Petroleum Asphalt)

The primary source of asphalt is from the refining of petroleum. In the refining process, the lighter components are extracted, leaving the more viscous or heavier portions of the crude petroleum as asphalt.

The breakdown of such crude is shown schematically in Fig. 2 below.

<b>Gasoline</b>
<b>Kerosene</b>
<b>Diesel Oil</b>
<b>Lube Oil</b>
<b>Asphalt</b>

**FIG. 2. COMPONENTS OF TYPICAL ASPHALT PRODUCING CRUDE OIL**

*Fig. 2. Components of typical asphalt producing crude oil*

Usually, asphalt base crudes vary in consistency (viscosity or hardness) and colour, from brown to black.

The residue of the distillation process of petroleum is not always asphalt, this will largely depend on the type of crude. Instead of asphalt, the residue can be wax (or paraffin) - paraffin base, or a mixture of asphalt and wax - mixed base crudes. In the case of mixed base crudes, special treatment is used to separate the asphalt from the wax. In the United States, crudes in California and other western parts are asphalt base, those from the middle part of the country are mixed base while those from Pennsylvania and other eastern areas are wax base. In Nigeria, the petroleum crude produced so far are mixed base or at times, wax base. Thus all the petroleum crude refined to produce asphalt at the Kaduna refinery are imported crudes, mostly from Venezuela.

According to Agoi-George and Ogunsola, Nigeria was spending about N315m per year for the importation of heavy crude oil from Venezuela used in Kaduna refinery for the production of lubricating oil, grease and bitumen during the mid-eighties (Agoi-George and Ogunsola, 1987). However, it was also claimed that the properties of the heavy oil extracted from Nigerian tar sands found in Ondo and Ogun States are similar to those of the heavy oils imported from Venezuela. Despite this claim and other claims that reserves of at least 31 billion barrels of oil equivalent are available at the tar sands deposits (Adegoke *et al*, 1974 and Synge, 1986) these deposits have not aroused the interest of Government, Oil Companies or other investors.

Table 2, according to the Ministry of Petroleum Resources, shows supply and consumption summary in Nigeria for bitumen for the period 1980 - 1992. It should be noted that the designed annual production capacity of Kaduna refinery for the production of bitumen is 689,700 metric tonnes. Thus, from Table 2, it is evident that the capabilities of the Kaduna refinery for the production of bitumen has not been realised during the period considered. It appears, however,

that the Kaduna refinery had mainly been producing bitumen for local consumption.

**TABLE 2: DETAILS OF ASPHALT PRODUCTION AT THE KADUNA REFINERY, 1980 – 1992\***

Year	Crude Oil Received	Crude Oil Processed	Asphalt Products Realized	Domestic Consumption (Asphalt)
1980	709,617	738,839	NA**	293,388
1981	2,028,079	2,093,655	NA	291,201
1982	1,848,660	2,061,479	NA	217,140
1983	2,749,701	2,504,119	58,174	158,068
1984	2,369,155	2,651,148	100,657	99,615
1985	2,919,224	3,072,305	151,953	90,938
1986	2,561,025	2,411,021	188,303	99,187
1987	3,268,370	3,273,766	131,613	99,530
1988	3,382,763	3,464,407	195,409	144,164
1989	2,531,072	2,523,357	130,085	100,780
1990	3,816,733	3,687,772	180,134	91,598
1991	3,451,662	3,491,319	NA	80,885
1992	2,699,378	2,660,490	99,304	179,345

All figures are in tonnes

\*\* NA – figures not available

Source: Statistical Bulletins of the Federal Republic of Nigeria (1980-92)

Also, besides bitumen, the capabilities of the refineries at Port Harcourt, Warri and Kaduna for the production of the various petroleum products have similarly not been realised (NNPC, 1986).

The general classification of asphalt and tar, is illustrated in Fig. 3 (on page 18).

#### 4. MANUFACTURING PROCESS

There are various ways of refining asphalt from petroleum, depending on the types of crude petroleum oil. For asphalt base crudes, a process known as vacuum and stream refining is used. On the other hand, the solvent deasphalting process is sometimes used to produce asphalt from mixed base crudes. For asphalts to be used in roofing, waterproofing and pipe coating, a further treatment of air-blowing as mentioned earlier is employed. Details of these manufacturing processes are readily available in the literature and will be considered as outside the scope of this presentation.

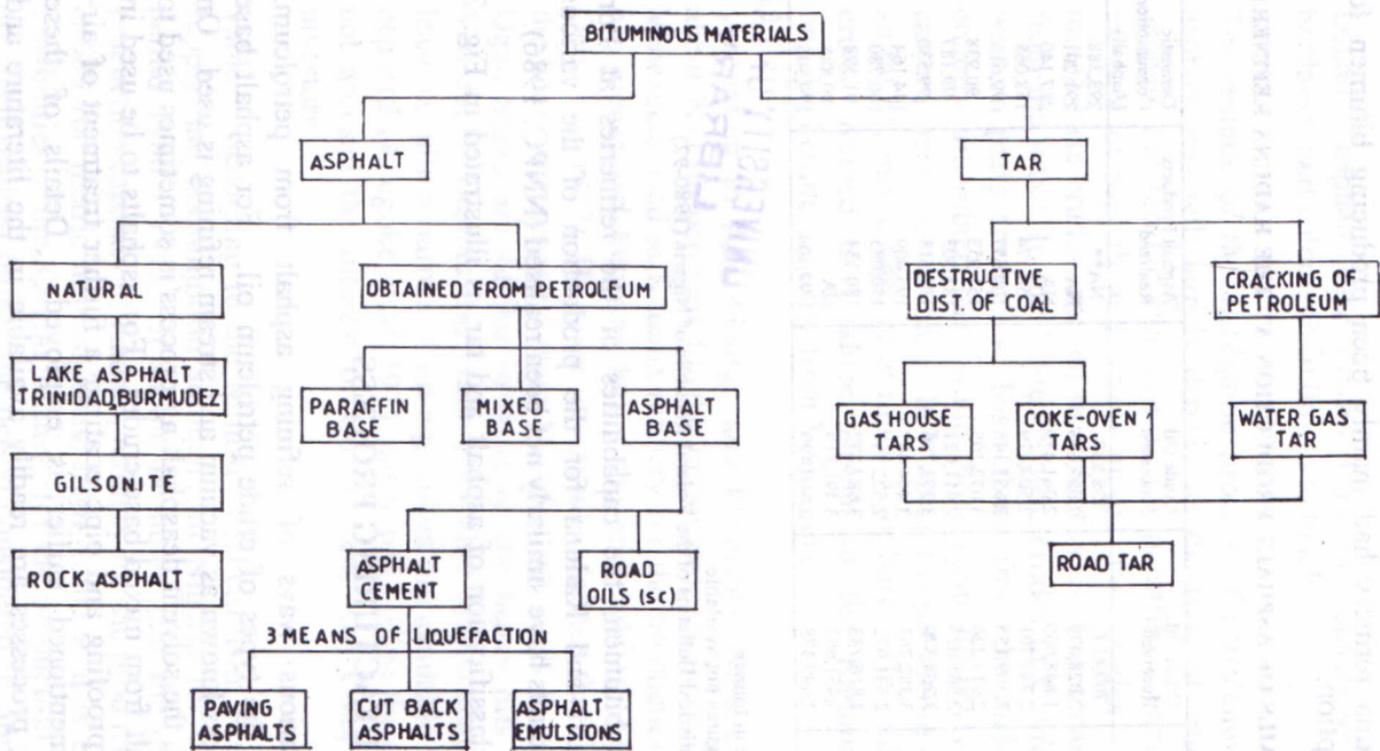


FIG.3. CLASSIFICATION OF BITUMINOUS MATERIALS

Fig. 3. Classification of bituminous materials

## 5. PAVING GRADE ASPHALT

Asphalt exists in three basic grades: Asphalt Cement, Liquid Asphalt and Asphalt Emulsion.

### 5.1 Asphalt Cement (AC)

This is the most viscous (hardest) grade used for constructing high quality pavements for heavily trafficked highways. It is usually produced directly from the refinery and it is solid at ordinary temperatures. It therefore requires heat treatment before mixing with aggregates.

**Classification by Penetration (Old Method).** The penetration is the distance a standard needle penetrates a sample of asphalt cement when a load of 100 g is placed on the needle for 5 seconds with the temperature of the asphalt cement maintained at 25°C. The unit of measurement is 0.01 cm. Thus, a needle penetrating a distance of 0.8 cm under the standard conditions classifies the asphalt as 80 pen. Common classification grades in decreasing order of hardness are 40/50, 60/70, 85/100, 120/150, and 200/300. Usually, the 60/70 pen. and the 85/100 pen. grade asphalts are used for asphalt concrete pavements for expressways and major roads.

**Classification by Kinematic Viscosity (New Method).** Common classification grades in decreasing order of hardness are AC40, AC20, AC10, AC5 and AC3.

Here, AC 40 asphalt has viscosity range between 4000 and 6000 stokes while AC 10 asphalt has viscosity range between 1000 and 1500 stokes.

### 5.2 Liquid Asphalt

Liquid asphalt is produced by blending asphalt cement with lighter petroleum products such as petrol or kerosene as solvent to produce asphalt that is liquid at ordinary temperature. This is usually referred to as cutback asphalt. Liquid asphalt can also be produced

directly from the refinery by making it sufficiently soft in which case it is called road oil.

The three grades of cutback asphalt are:

- (I) Rapid Curing (RC) : AC (85/100 pen.) + Petrol
- (ii) Medium Curing (MC): AC (100/150 pen.) + Kerosene
- (iii) Slow Curing (SC): AC (200/300 pen.)+ Lighter oils

Curing is the evaporation of the solvent from the asphalt - aggregate mixture after construction, leaving only the hard asphalt cement as aggregate binder.

The classification of liquid asphalt is illustrated in Fig. 4 (on page 21).

### 5.3 Asphalt Emulsion

Asphalt emulsion is produced by mixing asphalt cement with water in colloid mill so that asphalt is sheared and stays in suspension through the use of emulsifying agents.

(a) **Grades.** There are three grades of emulsions: Rapid Setting (RS), Medium Setting (MS) and Slow Setting (SS).

The setting or breaking time is the time it takes the dispersed asphalt particles to integrate or recombine to form a continuous film of asphalt cement after water must have evaporated. Thus, the stronger the emulsifying agent, the slower the setting rate.

Some of the grades of RS and MS emulsions, produced by using 120/150 or 150/200 pen AC and in increasing percentage of asphalt, have been classified as RS-1, RS-2 and RS-3, and MS-1, MS-2 and MS-3.

The SS emulsions produced by using 40/50 or 60/70 pen AC are classified as SS-1 and SS-2 (or SS-1h).

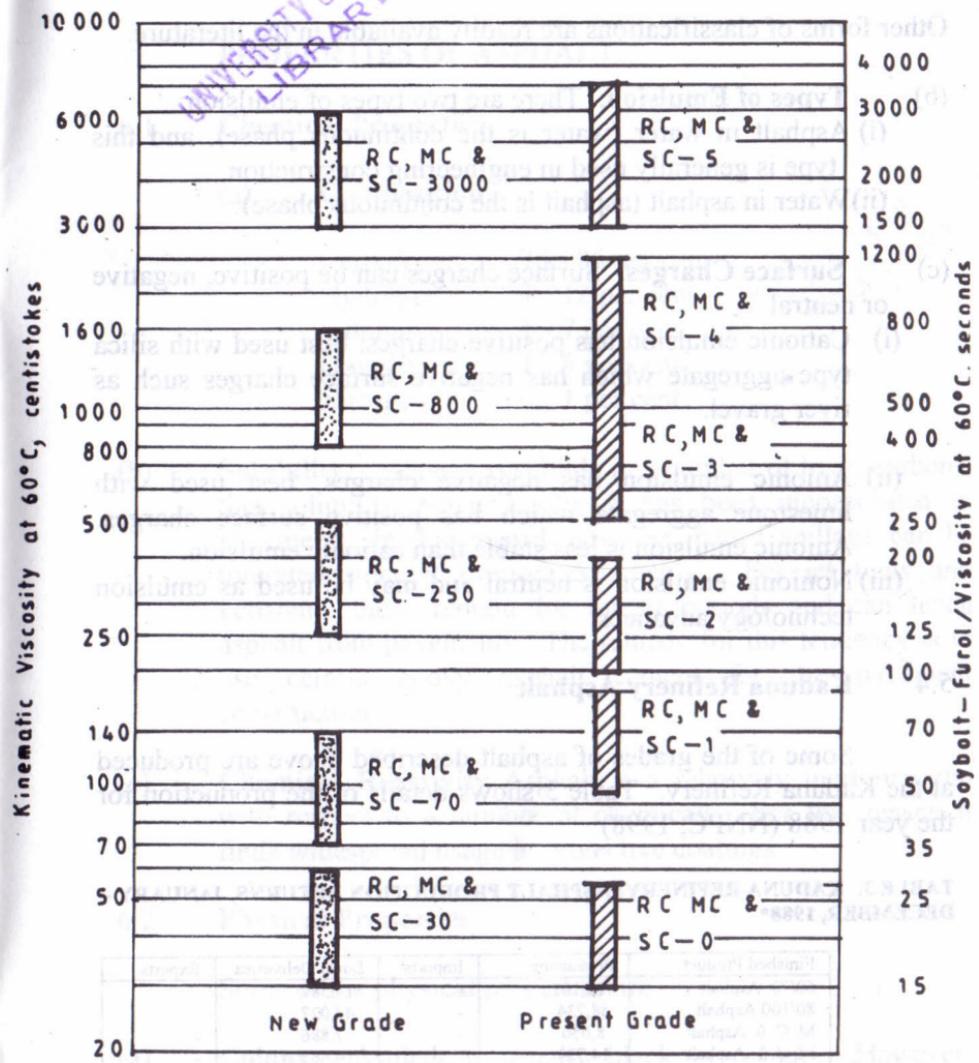


FIG.4. COMPARISON OF PRESENT AND NEW LIQUID GRADES OF ASPHALTS

Fig. 4. Comparison of present and new liquid grades of asphalts

Other forms of classifications are readily available in the literature.

- (b) **Types of Emulsion.** There are two types of emulsion:
- (i) Asphalt in water (water is the continuous phase), and this type is generally used in engineering construction.
  - (ii) Water in asphalt (asphalt is the continuous phase).
- (c) **Surface Charges.** Surface charges can be positive, negative or neutral.
- (i) Cationic emulsion has positive charges, best used with silica type aggregate which has negative surface charges such as river gravel.
  - (ii) Anionic emulsion has negative charges, best used with limestone aggregate which has positive surface charges. Anionic emulsion is less stable than cationic emulsion.
  - (iii) Nonionic emulsion is neutral and may be used as emulsion technology advances.

#### 5.4 Kaduna Refinery Asphalt

Some of the grades of asphalt described above are produced at the Kaduna Refinery. Table 3 shows details of the production for the year 1988 (NNPC, 1998).

**TABLE 3: KADUNA REFINERY: ASPHALT PRODUCTION RETURNS, JANUARY – DECEMBER, 1988\***

Finished Product	Production	Imports	Local Deliveries	Exports
60/70 Asphalt	112,107	-	115,587	-
80/100 Asphalt	48,234	-	44,027	-
M. C. 0. Asphalt	8,050	-	7,886	-
M. C. 1. Asphalt	14,784	-	14,663	-
S125 Asphalt	15,234	-	13,994	-

\* All figures are in tonnes

Source: NNPC (1988)

## 6. PROPERTIES OF ASPHALT

### 6.1 Chemical Properties

#### (a) Composition

Carbon:	70 - 85 per cent
Hydrogen:	7 - 12 per cent
Sulphur:	1 - 7 per cent
Oxygen:	1 - 5 per cent
Nitrogen:	0 - 1 per cent

(b) **Solubility.** Asphalt is soluble in a number of hydrocarbons, this solubility remains after it has been incorporated in pavements. In this regard, however, petrol spillage can be tolerated since it evaporates quickly. For jet fuels and kerosene, these remain for longer periods and can leach asphalt from pavements. The remedy for this tendency is to use certain epoxy asphalt, cement for the pavement construction.

(c) **Chemical Reactivity** Asphalt is a relatively inert material with respect to a number of chemicals. For this reason it finds widespread usage in protective coatings.

### 6.2 Physical Properties

Some of the physical properties are:

(a) **Colour.** Asphalt is usually black in colour. However, coloured asphalt for special purposes can be produced at high costs, for example, red, green, blue or even white.

(b) **Specific Gravity (SG).** The specific gravity of manufactured asphalt varies from 0.95 to 1.05, while that of natural asphalt is generally higher. Specific Gravity is used in the calculation of weight-volume relationship for mixtures.

Other important physical properties are surface and interfacial tension, specific heat and the coefficient of cubical expansion.

### 6.3 Rheological Characteristics

Rheology is the study of materials whose deformation characteristics vary with load and time rate of load application. The stress/strain characteristics of asphalt are time dependent. Asphalt is also thermoplastic as its consistency or degree of hardness varies with temperature. These characteristics of asphalt affect its performance as a pavement material.

Engineering materials can be elastic or viscous, while many others such as asphalt, are neither purely elastic nor purely viscous in behaviour. When loaded rapidly, they exhibit elastic behaviour and when loaded very slowly, they exhibit viscous behaviour. For an intermediate range of loading rate they exhibit a combination of elastic and viscous behaviour and may therefore be referred to as viscoelastic.

Attempts made in the past to describe the behaviour of asphalt trying the Maxwell model, the Kelvin model and the Burgers model indicated that the Burgers model (Fig 5, page 25) best describes the material. It has also been observed by various researchers that some asphalts conform to Newtonian behaviour while many others deviate considerably from it.

## 7. STANDARD TESTS

Standard tests are available for the various grades of asphalt and specifications have been evolved on the bases of these standard tests. Reference can be made to standard literature on asphalts in this regard, particularly ASTM, AASHTO and BSI. The standard tests can be itemised as follows:

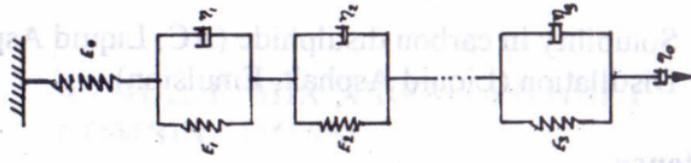


Fig. 5c. Complex model

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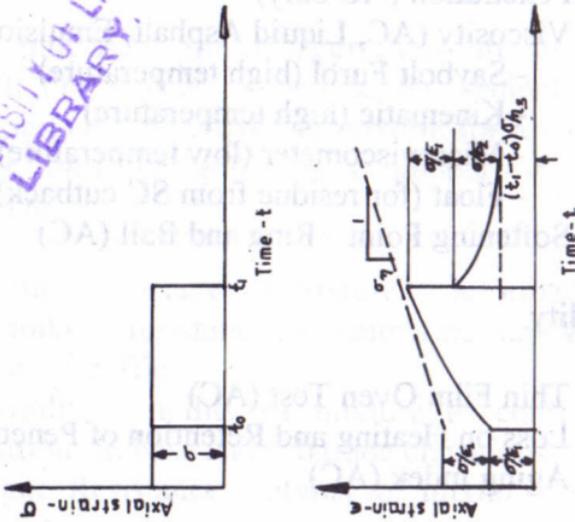


Fig. 5b. Axial stress and strain vs time relationships for Burger model subjected to stress in time interval  $t_0$  to  $t_1$

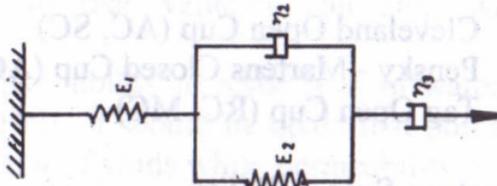


Fig. 5a. Burgers (4-element) model

Fig. 5 (a) Burgers (4-element) model

Fig. 5 (b). Axial stress and strain vs time Relationships for Burger model subjected to stress in time to  $t_0$   $t_1$ .

Fig. 5 (c) Complex model

### 7.1 **Composition**

- (a) Solubility in carbon disulphide (AC, Liquid Asphalt)
- (b) Distillation (Liquid Asphalt, Emulsion)

### 7.2 **Consistency**

- (a) Penetration (AC only)
- (b) Viscosity (AC, Liquid Asphalt, Emulsion)
  - Saybolt Furol (high temperature)
  - Kinematic (high temperature)
  - Microviscometer (low temperature)
  - Float (for residue from SC cutback)
- (c) Softening Point - Ring and Ball (AC)

### 7.3 **Durability**

- (a) Thin Film Oven Test (AC)
- (b) Loss on Heating and Retention of Penetration (AC)
- (c) Aging Index (AC)

### 7.4 **Safety - Flash Point Tests**

- (a) Cleveland Open Cup (AC, SC)
- (b) Pensky - Martens Closed Cup (AC)
- (c) Tag Open Cup (RC, MC)

### 7.5 **Temperature Susceptibility**

Penetration Ratio (AC)

### 7.6 **Rate of Setting or Curing**

- (a) Distillation (Liquid Asphalts)
- (b) Demulsibility (Asphalt Emulsions)

## 7.7 Miscellaneous

- (a) Ductility (AC)
- (b) Specific Gravity (AC, Liquid Asphalts)

## 8 ASPHALT MIXTURES (ASPHALT - AGGREGATE COMBINATIONS)

### 8.1 Desirable Properties

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For paving purposes, graded aggregates are usually mixed with asphalt, with the asphalt serving as the cementing material. To properly design an asphalt paving mixture for a specific application, consideration must be given to a number of desirable mixture properties. These include:

- (a) Stability - resistance of mixture to deformation under load.
- (b) Durability - resistance to weathering, aging and the abrasive action of traffic.
- (c) Flexibility - ability of mixture to conform to long-term variations in base and subgrade elevations.
- (d) Fatigue Resistance - ability of mixture to bend repeatedly without fracture.
- (e) Skid Resistance - ability of mixture to provide sufficient resistance so that vehicles can stop within reasonable distances.
- (f) Permeability - ability to resist flow of water and air through mixture. Here, it should be noted that porosity is a measure of the amount of voids while permeability is a measure of the connection of the voids.
- (g) Workability - ability of mixture to present a smooth-finished surface texture when placed and compacted.
- (h) Fracture Strength - maximum strength the mixture exhibits when subjected to tensile stress.

### 8.2 Factors Affecting Properties

Factors affecting the above properties vary with each property and

they include asphalt content and type; aggregate type, shape, texture and gradation; amount of compaction (density); type, magnitude and frequency of loading; environmental effects, etc.

### 8.3 Mixture Design

Standard tests are available for design and control of the mixtures in respect of the above various desirable properties. These tests and specifications are contained in various manuals, particularly the Asphalt Institute and the ASTM. One of the most commonly used asphalt mixture design procedures all over the world, including Nigeria, is the Marshall method.

Another design procedure, the indirect tensile test method, has been receiving tremendous attention within the last three decades because of its several advantages over the Marshall method (Kennedy and Hudson, 1968; Anagnos and Kennedy, 1972; Adedimila and Kennedy, 1975; Adedimila, 1980; Adedimila, 1986; and Adedimila and Ashade, 1993).

### 8.4 Types of Asphalt - Aggregate Combinations

(a) **Asphalt Concrete** - a mixture of heated asphalt cement and graded aggregate. Asphalt content is usually between 3 and 10 per cent by weight of mixture. Asphalt concrete is used for heavily trafficked highways. It can be thin lift (in layers of surface, base and subbase courses) or thick lift (one single course) over compacted subgrade.

(b) **Surface Treatment** - a mixture of liquid asphalt and aggregates used for low traffic situations. It is less expensive than asphalt concrete. Examples are:

(i) **Surface Dressing** - alternative application of asphalt and aggregate to a newly prepared roadbed.

(ii) **Seal Coat** - single application of bituminous materials followed by a light spreading of fine aggregate or sand to an existing pavement.

- (iii) Bituminous Macadam (or Penetration Macadam) - a reverse procedure of surface dressing, that is, application of aggregate (compacted) plus asphalt which penetrates the aggregate and then small stones to fill the spaces and final rolling.

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## 9. ONDO STATE NATURAL BITUMEN DEPOSITS

The naturally occurring bituminous materials of the Ondo State deposits are found in two basic forms on site, namely;

- (i) Bitumen seepages from wells which yield 'plain' bitumen, i.e. bitumen not noticeably associated with sand. This is soft at ordinary temperature and is therefore low viscosity bitumen.
- (ii) Seepages and outcrops of bitumen-impregnated sands from which bitumen can be extracted by suitable processes. This is generally referred to as "tar sands" but should more appropriately be called "bitumen sands" since tar can not occur in nature. However, to avoid unnecessary confusion, the term "tar sand" will continue to be used throughout this lecture.

While petroleum crude oil which produces both energy and non-energy derivatives is usually described as a conventional energy source, bitumen seepages and tar sands, both bituminous materials and heavy hydrocarbon, are generally described as a non-conventional energy source.

### 9.1 Previous Work on the Bitumen Deposits

Prospecting for oil and bitumen in Nigeria started long before the birth of Nigeria as a political entity as we know it today (Onoh, 1983, Nwaochei, 1986 and NNPC, 1990). According to Onoh (1983), the Nigerian Bitumen Company, a German Company started exploration for bitumen in 1908 along the coastal region stretching from

Okitipupa in Ondo State to Lagos. The first discovery of hydrocarbon in 1909 was on the tar sand belt in the coastal area of the Western part of the country (Etete, 1995). Although very heavy crude oil was produced from wells sunk on the deposit, the discovery of light to medium oil in commercial quantity at Oloibiri in the Niger Delta area in 1956 by Shell BP, a company formed in 1946 by Shell D'Arcy which started exploration in 1937 in partnership with British Petroleum, caused the abandonment of the exploration of the bitumen sands (NNPC, 1990, Etete, 1995).

Attention has however, been drawn to the natural bitumen deposits of Ondo State by work done in one form or another by certain groups, organizations and individuals. Even though much of these efforts (especially the earlier attempts) have been of a fragmentary manner; the reliability of information on the materials has been improving especially in recent years resulting in desirable growth of useful information on the deposits. Some of the findings have been documented in papers published in reputable scientific and technical journals as well as published reports of the proceedings of international conferences while others have been confined to unpublished reports which remain largely obscure.

Notable amongst the earlier workers, besides the defunct Nigerian Bitumen Corporation were the Tennessee Nigeria Inc. (Durham and Pickett, 1966), Crockett and Wescott (1954), and Coursey, *et al* (1963). Amongst the more recent workers are the geological survey team from the University of Ife, now Obafemi Awolowo University, Ile-Ife ably led by Professor . O. S. Adegoke (1974, 1976, 1980, 1982, 1985), some limited geological work by Agagu (1985), and also some limited engineering studies by Adedimila (1987), and Adedimila and Olagoke (1990).

According to Adegoke and his team, the natural bitumen deposits are located within a belt spanning from the East of Ijebu-Ode in Ogun State, through Okitipupa and Ifesowapo areas in Ondo State to the Western margin of Delta State (Fig. 6, page 32). The asphalt-bearing zone is 120 kilometres long and about 6 kilometres wide and the

thickness ranges from 0.5m to over 40m with an average of about 6m. Also, according to Adegoke *et al* (1974), the estimated recoverable reserves of the tar sands of the Western State of Nigeria amount to 31 billion barrels of oil equivalent which is almost double the estimated reserves of crude oil in Nigeria. In later investigations, a conservative estimate of the recoverable asphalt from the bituminous sands was found to be of the order of  $270 \times 10^6$  metric tonnes (Adegoke, *et al*, 1980 and Adegoke and Ibe, 1982) which compares favourably with other major deposits elsewhere as shown in Table 1. Figure 7 (page 34) shows a seismic section and borehole data along the E – W traverse (Adegoke, *et al*, 1980)

Other contributors to the existing literature on the physico-chemical properties of Nigeria's natural bitumen include Oshinowo, *et al* (1982), Oluwole, *et al* (1985), Ekweozor and Nwachukwu (1989) and Ekweozor (1990)..

## 9.2 Engineering Studies

Apart from exploratory studies and geological investigations, a few engineering studies have also been carried out to appraise the quality of material from the bitumen-rich areas. Unfortunately however, the effectiveness and reliability of most of these attempts and the corresponding findings and assessments have been adversely affected by one major constraint or the other notable among which have been the seemingly recurring inability to obtain sufficient quantity and variety of samples from the bitumen-rich zones and an often severe limitation of specialised equipment for core-sampling, in-situ and laboratory testing.

### (a) Tar Sands

The most recent engineering study known to have been carried out and for which findings and results were published is that by Adedimila (1987). Laboratory tests were performed in order to analyse the major components of the bituminous sands as well as to investigate engineering properties such as Marshall stability and flow, gradation, indirect tensile strength and compressive modulus.

Fig. 6. Bitumen seepage area (after Adegoke et al, 1980)

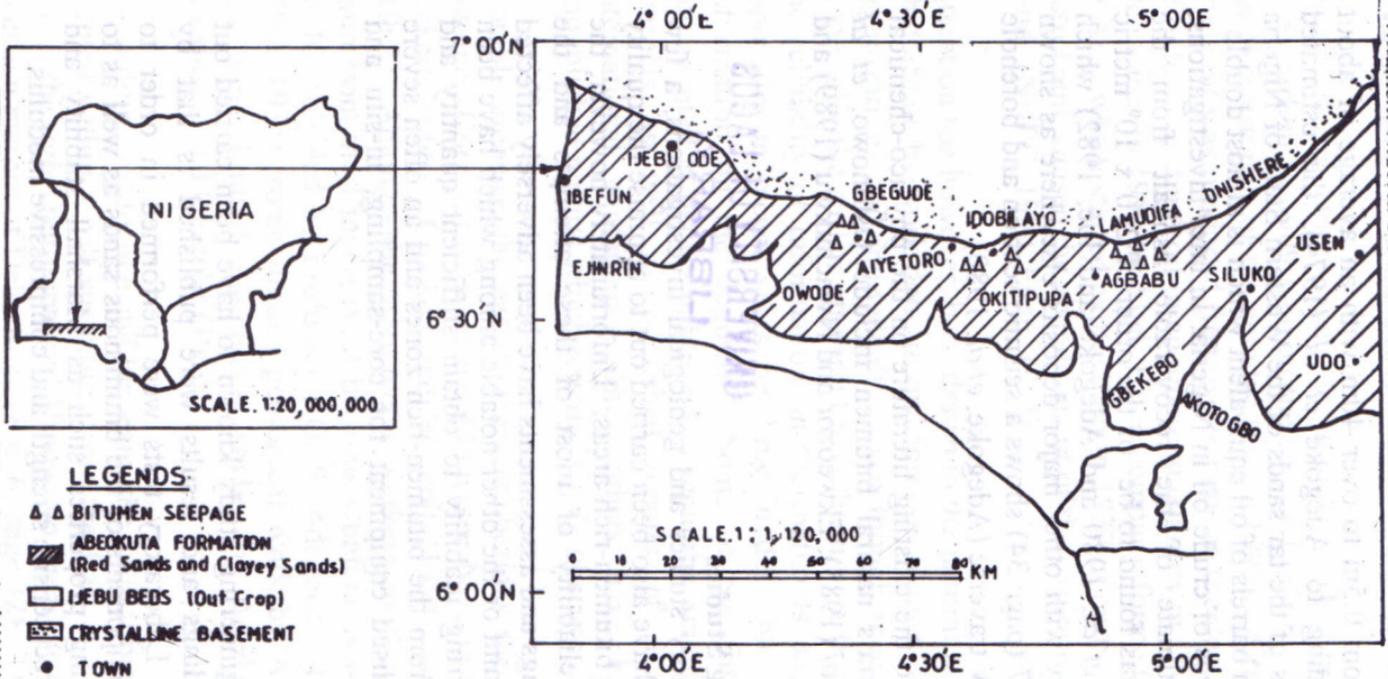


FIG. 6. BITUMEN SEEPAGE AREA (After Adegoke et al, 1980)

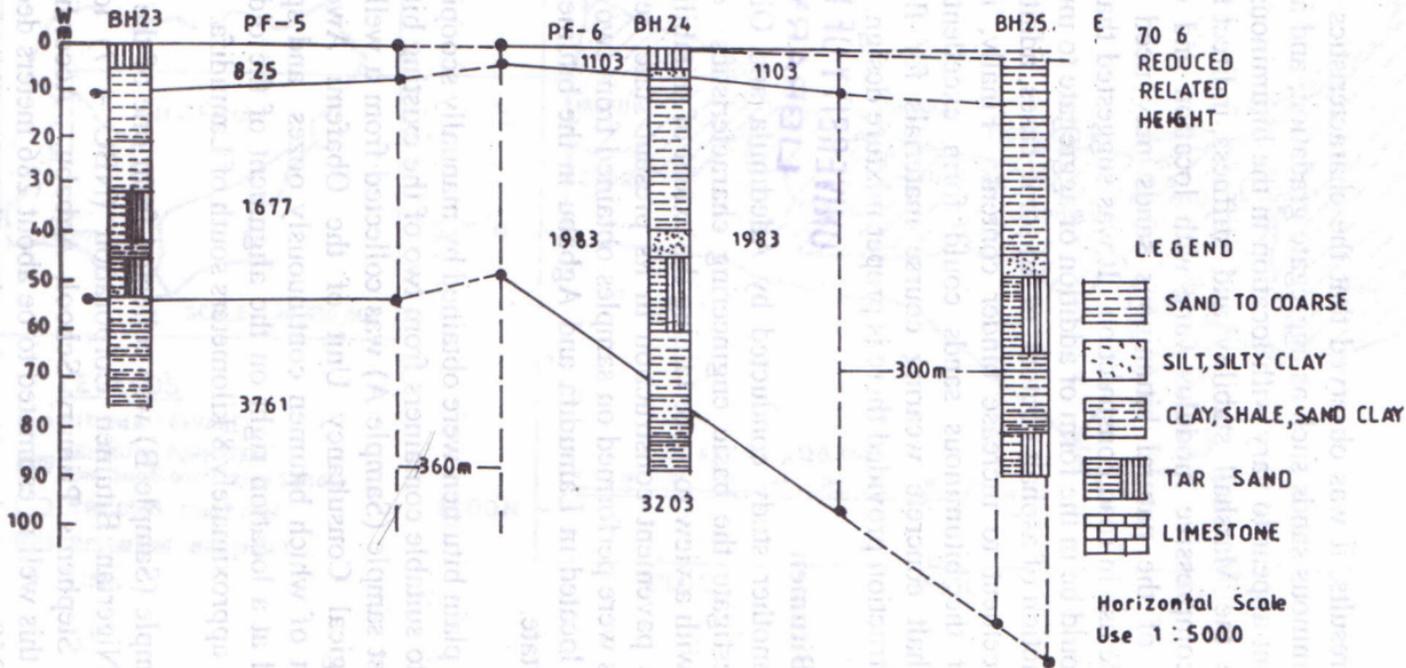
From the test results, it was observed that the characteristics of the Okitipupa bituminous sands such as aggregate gradation, and asphalt type and amount appear to vary with location in the bituminous sand horizon, while the Marshall stability and stiffness, indirect tensile strength and compressive modulus vary with location and coring depth. Some of the natural bituminous sands may need to be modified before use in road construction. It was suggested that such modification could be in the form of addition of aggregate to improve gradation, reduction of asphalt content, or, in some cases, addition of more asphalt cement to increase binder content. Finally, it was concluded that the bituminous sands could form excellent base course or asphalt concrete wearing course materials for flexible pavement construction provided there is proper mixture design.

(b) **Plain Bitumen**

Similarly, in another study conducted by Adedimila and Olagoke (1990) to investigate the basic engineering characteristics of the plain bitumen with a view to ascertaining the extent of suitability for use in flexible pavement construction in its present state, relevant laboratory tests were performed on samples obtained from two of the bitumen wells located in Lamudifa and Agbabu in the bitumen-rich area of Ondo State.

Samples of the plain bitumen were obtained by manually scooping up the material into suitable containers from two of the existing bitumen wells. The first sample (Sample A) was collected from a well sunk by the Geological Consultancy Unit of the Obafemi Awolowo University out of which bitumen continuously oozes and spreads across the road at a location right on the alignment of the old Otu-Oluagbo Road, approximately 8 kilometers south of Lamudifa.

The second sample (Sample B) was collected from one of the wells sunk by the Nigerian Bitumen Corporation (NBC - 7) located opposite Saint Stephen's Primary School, Agbabu. According to Agagu, (1985) this well is estimated to be about 286 meters deep. It is lined with a 250mm steel casing rising about 1 meter above ground level and is filled with bitumen to approximately ground level.



**FIG. 7. SEISMIC SECTION AND BOREHOLE DATA ALONG AN E-W TRAVERSE.**

*Fig. 7. Seismic section and borehole data along an E-W traverse*

The following laboratory tests were performed to evaluate the engineering characteristics of the bitumen samples:

- (a) Tests of physical characteristics:
  - (i) Specific gravity test using the pycnometer method
  - (ii) Flash point test using the cleveland open cup apparatus.
- (b) Consistency tests
  - (i) Penetration test using the penetrometer apparatus
  - (ii) Softening point test using the ring-and-ball apparatus
  - (iii) Viscosity test using the standard tar viscometer
  - (iv) Penetration index test using nomograph developed for Shell Development Company.

The results of the tests indicated that while most of the naturally occurring bitumen might be directly suitable for use in road works in their present state, some others require suitable treatment or modifications. Such treatment or modification may, as in the case of Trinidad Lake asphalt, and, according to Krebs and Walker (1971), take the form of refining by heating to sufficiently high temperatures to drive off water and entrapped gases responsible for the crackling sounds and foaming of the samples during heating.

It should be noted that similar conclusions were made by Adedimila (1987) in his study on tar sands obtained from the same area. However, it is important to know that the two studies had been rather limited in scope, particularly on the coverage of the samples tested. It is therefore of utmost importance that elaborate studies on both plain bitumen and tar sands covering wider areas of the bitumen horizon be conducted to evolve adequate design for the construction materials. Such studies, necessarily, must be adequately funded.

### 9.3 Economic Considerations

The abundance of the naturally occurring bitumen in the Western part of Nigeria has been discussed. In addition, the various uses of bitumen have been highlighted and attention has been drawn to the apparent long neglect of the natural bitumen in the area of development and utilization.

The apparent neglect may not significantly be due to political considerations. A good explanation from the economic point of view has been offered by Iwuyemi (1990). While it is believed by many that there would be potential increase in foreign exchange earnings that would accrue from more oil export as tar sand, if developed and utilized, will displace part of the domestic crude oil requirements in meeting domestic energy and non-energy demand, as well as the substitution of tar sand for the imported crude used in domestic (Kaduna) refinery, Iwuyemi submitted that to the economist, the comparative disadvantage of tar sand vis-à-vis crude oil in meeting both domestic and foreign current and future demand must be considered and he went further to show that careful considerations of the economics of tar sand development can add considerable complexity to what seemingly looks like a straight-forward policy issue. Rather, according to him, the relative price of tar sands, and the cost competitiveness compared to petroleum crude oil and other conventional and non-conventional energy sources, are the critical parameters in the determination of the economic value of the tar sand development project. Stressing this point further, Iwuyemi asked: "If investment in tar sand is profitable, why is the risk capital not available and political pressures have to be applied for its early development?" He then concluded that the major economic factor that has and would continue to impede the exploitation of the substantial reserve of tar sand is the availability of domestic crude oil, which is cheaper and more profitable to exploit

While I personally do not intend to contest the expert economist's submission partially highlighted above, the issue of the diversity of usage of the tar sands and plain bitumen, particularly the use in pavement construction where, at present Nigeria wholly depends on imported crudes to produce bitumen must be emphasized. In addition, the need to consider non-economic factors and for government to subsidize, if need be, like in other areas of the Nation's economy, which factors were similarly recognized and well appreciated by Iwuyemi, it is strongly believed that the development and utilization of the bitumen reserves in the Western part of the

country should have long been given favourable consideration by the Federal Government.

One is therefore particularly happy to note that early in 1999, the Federal Government, through the Ministry of Solid Minerals Development had finally set up a National Committee to coordinate and implement the development of the Bitumen Project.

## 10. RECOMMENDATIONS

- (i) It is sad to note that at present, there is not a single laboratory in Nigeria, either in tertiary institutions or other government establishments such as the Ministries (particularly FMW & H), Nigerian Building and Road Research Institute (NBRRI), etc., that is adequately equipped for tests on bituminous materials. The few that possess scanty items of equipment are such that the equipment are either obsolete, not functioning or can at best be used for demonstration purposes. There is very few that can be used to conduct meaningful and reliable research. Therefore, there is need to establish standard laboratories in some of the Universities, Polytechnics and other Research Agencies and necessary engineering investigations to properly characterise the natural and manufactured bitumen must be conducted.
- (ii) It may not be in the best interest of Government to concentrate on road and other construction works without any attention to research. Research findings can significantly reduce the present construction costs. Therefore Government should address this area of activity that has for a very long time been treated with kid gloves, short of saying outright neglect.
- (iii) Research funding, like in other areas requiring huge expenditure, should not be left to Government alone. There is no Government in the world that can single-handedly cater for all its research needs. Usually agencies, organisations, foundations and even individuals play active roles in the

funding of research. This practice is highly desirable in Nigeria.

- (iv) Government and multi-national organisations must encourage immediate implementation of research findings rather than keeping such findings in the archives. Immediate implementation of research findings will give the opportunity for monitoring performance and establishing areas of possible improvement or further research.
- (v) Government establishments must set up and maintain data banks to ease information retrieval. There should be efficient local and international information management through widespread connections to internet and other information management systems.
- (vi) The training of asphalt technologists is very important. The dearth of such technologists cannot continue without having unpleasant consequences particularly in pavement construction and maintenance either by contract or by direct labour. Therefore, training institutes or centres, probably attached to the tertiary institutions, the Nigerian National Petroleum Corporation or the newly established Bitumen Implementation Project must be put in place.
- (vii) Government should establish special tax fund for training, research and development in bitumen technology where all the companies involved with petroleum exploration and exploitation can be "exploited". Our refineries, particularly that in Kaduna where asphalt is produced should be regularly maintained and made functional at all times, using part of this fund.
- (viii) Efforts should be made to source for other petroleum crudes. The way God has blessed Nigeria gives one the confidence that somewhere in Nigeria, asphalt-yielding crudes must be available. If the United States of America had limited its

exploration efforts to the eastern parts of that country, it would not have been one of the countries with the largest reserve of bitumen-yielding crude today. The bitumen producing crudes are mostly in the western parts of that country. Also, the fact that natural asphalt is available in Nigeria and bearing in mind that natural asphalt is a product of the fractional distillation of asphalt-yielding crude petroleum over long period of time, it can be inferred that asphalt-base crude must of necessity exist in Nigeria, except, of course, the rare situation in which all available asphalt-base crudes had already been subjected to fractional distillation.

- (ix) The Federal Government should consider not only the economic factors but also the non-economic factors, and must be prepared to subsidise, like in other sectors of the economy, if the plain bitumen and the bitumen sands of the western parts of the country must be developed and utilised. Thus, the establishment of the Bitumen Implementation Project, a Federal Government Agency in Ondo State is a welcome development. However, the Federal Government should grant the Agency the status of a parastatal for effectiveness. Also the Federal Government must immediately enact appropriate laws regulating the exploitation of the native bitumen, and approve the commencement of a comprehensive study and evaluation of the likely environmental impact of the bitumen project.

## 11. CONCLUSION

- (i) Bitumen deposits are available in the coastal areas of western Nigeria in commercial quantities. These are either bitumen seepages from wells or seepages and outcrops of bitumen-impregnated sands usually referred to as "tar sands" but which should be more appropriately called "bitumen sands".
- (ii) Not all natural bitumens are good for road construction purposes in their natural forms. Limited engineering studies on bitumen samples from deposits in the western part of

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Nigeria confirm this. However, many of the deposits are excellent construction materials while those that are not as good in their natural forms can be modified to produce adequate materials for road construction and other uses.

- (iii) The long delay in the development and utilisation of the natural bitumen of the western part of Nigeria by the Federal Government might be due, in part, to economic considerations, especially when compared with crude petroleum oil in relation to energy and non-energy demand. However, Nigeria's natural bitumen deposits, if exploited, can earn the much desired foreign exchange in addition to serving as local pavement construction materials.

## 12. **ACKNOWLEDGEMENTS**

My colleagues at the University of Lagos including the laboratory and the secretarial staff have contributed immensely, not only during the preparation of this lecture, but also during the period I was involved with various research programmes in the University. I thank them all most sincerely. My profound appreciation goes to Mr. A. J. Abimbola of Ondo State Polytechnic, Owo, who assisted in the collection of reference materials. I also thank Professor. O. S. Adegoke and Professor Bankole Ako, formerly and currently of Obafemi Awolowo University, Ile-Ife, respectively, for making available their research materials.

I thank all members of my family for their support and understanding at all times.

Finally, I am grateful to God Almighty, our creator, for His protection, love and abundant blessings.

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