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# CHARACTERIZATION OF PENETRATION-GRADE BITUMEN BLENDED WITH LIGHTER PETROLEUM PRODUCTS

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## ABSTRACT

Low penetration-grade bitumen is mixed with each of three lighter petroleum products (kerosene, diesel, and lubricating oil) to produce blended bitumen for priming the surface of road during construction of road pavement. The flash point, penetration, and viscosity, of the various bitumen blends are investigated experimentally. The penetration of each bitumen blend increases while both the viscosity and flash point decrease as the concentration of diluent in the bitumen blend increases. These effects are more pronounced with kerosene as the diluent, followed by diesel, and then lubricating oil. The volume of each diluent used in the analysis varies from 1ml to 10ml in steps of 1ml per 100ml of pure bitumen and the corresponding ranges of flash point of the various bitumen blends are 158°C-56°C for kerosene, 202°C-148°C for diesel, and 221°C-210°C for lubricating oil; the corresponding ranges of penetration of the bitumen blends are 105pen-230pen for kerosene, 78pen-230pen for diesel, and 66pen-212pen for lubricating oil; the corresponding ranges of viscous flow time are 4.0s-1.4s for kerosene, 4.3s-2.3s for diesel, and 4.3s-3.2s for lubricating oil. It is shown that kerosene is the best of the three diluents considered in the analysis for preparing blended bitumen for priming during road surfacing.

**KEYWORDS**: Penetration-grade bitumen; Kerosene; Diesel; Lubricating oil; Viscosity; Flash point.

## 1. INTRODUCTION

Bitumen is a hydrocarbon mixture which remains after vacuum distillation of crude oil. It is a complex mixture of organic and inorganic compounds (Garcia-Morales et al., 2004), and is widely used as binder in road surfacing (O'Flaherty, 2002). Bitumen may be separated into asphaltenes and maltenes. Asphaltenes are defined as the black-coloured fraction of bitumen that is insoluble in *n*-heptane. Maltenes composed of saturated hydrocarbons, aromatic compounds, and resins, are soluble in *n*-heptane (Whiteoak, 1990). It is generally believed that bitumen can be pictured as a colloidal dispersion where the components of highest molecular weight, the asphaltenes, are dispersed into a medium constituted by the remaining components, the maltenes (Navarro et al., 2007).

Unmodified bitumen is highly susceptible to change in temperature due to its rheological properties (e.g. viscosity and stiffness). At low temperatures the bitumen becomes brittle and cracks, while at high temperatures it softens with the result that the bitumen binder either migrates to the surface or the pavement tends to rut (permanent deformation) under stress (Chaala et al., 1996). These deficiencies of bitumen can be minimized by the addition of polymer which is known to endow bitumen with viscoelastic behaviour (Navarro et al., 2007). Polymer-modified bitumens are designed to prevent the three main causes of poor performance and loss of structural integrity of asphaltic pavements: rutting, as a consequence of the accumulated plastic deformation due to both high loads and/or high temperatures; fatigue cracking, caused by repetitive loading; and thermal cracking, due to embrittlement caused by low temperature (Navarro et al., 2007). There is a lot of literature on modification of bitumen as paving material and more work in this area can be found in Yousefi (2004), Jew et al. (2003),), Giavarini et al. (1996), Fawcett et al. (1999), Fawcett and McNally (2000), and Yousefi et al. (2000). This study is not concerned with modification of bitumen to improve the performance of pavement as discussed above.

The point of the present paper is that before placing bituminous pavement on a road, the surface of the road is often 'primed' with bituminous material to coat and bind dust on the surface and also to plug capillary voids in the soil in order to prevent upward movement of water which weakens pavement causing deformation when load is applied. This requires the use of penetration-grade bitumen which vary from very viscous to semi-solid material at ambient temperature. It is therefore, normally heated to a high temperature (typically 140°C-180°C) in order to lower its viscosity and increase the penetration (O'Flaherty, 2002). However, when the bitumen is mixed with a solvent (or diluent) say kerosene, the viscosity of the bitumen is reduced, its penetration increases, and the bitumen blend may be heated at a much lower temperature. The process of blending bitumen with gasoline, kerosene, or diesel is called *cutting back* and the mixture is called *cutback*

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*bitumen*. The rate at which the diluent evaporates from cutback bitumen when applied to road surface is called *curing*. Cutback bitumen are of different grades depending on the type of diluent such as gasoline (rapid curing), kerosene (medium curing), and diesel (slow curing). The presence of diluent also reduces the flash point of the blended bitumen to a level that may be considered dangerous during field operation. The flash point, therefore, is the parameter used in evaluating the hazard level of bitumen in terms of flammability.

The recommended penetration for bitumen used for most road surfacing work is 100-150pen (Kadiyali, 1997; Brennan and O'Flaherty, 2002). Such high penetration-grade bitumen is scarce in Nigeria (Adedimila, 2004), resulting in the use of the available low penetration-grade bitumen (e.g. 45pen from Monier Construction Company (MCC), Port Harcourt, Nigeria) for construction of bituminous pavement and preparation of cutback bitumen. Studies on the properties of bitumen blended with lighter petroleum products (kerosene, diesel, gasoline, and lubricating oil) are scarce in the literature. It is the purpose of this paper to (i) blend low penetration-grade bitumen with kerosene, diesel, and lubricating oil, (ii) determine experimentally the viscous flow time, penetration, and flash point, of the various bitumen blends, and (iii) select the best of the three lighter petroleum products considered in the analysis for preparing blended bitumen used for priming during construction of road pavement.

## 2. MATERIALS AND METHODS

### *2.1. Materials*

The materials used for the experiments are bitumen with average penetration of 45pen (obtained from Monier Construction Company, Port Harcourt, Nigeria); kerosene, diesel, and lubricating oil (obtained from Petroleum Products Marketing Company, Port Harcourt, Nigeria); 250ml beakers, electric heater, measuring cylinder, thermometer, stop watch, tin-cup, standard penetrometer apparatus, standard tar viscosity apparatus, and Pensky-Martens flash point apparatus.

### *2.1.1 Sample preparation*

According to ASTM standard (ASTM, 1978), the semi-solid pure bitumen collected from Monier Construction Company, Port Harcourt, was first heated at low temperature (about 67$^0$C) to transform it to liquid. Low-temperature heating is recommended to avoid change in properties of the bitumen at high temperature (Emesiobi, 2000; Oglesby and Hicks, 1982). The whole semi-solid material does not change to liquid at the same time, so samples were prepared whenever enough liquid was formed during the heating process until the required number of samples was obtained. 100ml of the pure liquid-bitumen was measured into a cup and mixed with 1ml of a given lighter petroleum product, say kerosene, and the mixture well stirred to ensure uniform blend. This process was repeated with 2ml to 10ml of kerosene in steps of 1ml, to obtain ten (10) samples of bitumen/kerosene blend for the experiments. After conducting all necessary experiments using the first ten samples with kerosene as diluent, the same number of samples with diesel and lubricating oil as diluents were prepared using the procedure described above for kerosene. The samples prepared in this way were used for penetration and viscosity tests only. In the case of flash point test, each sample was prepared as described above using the cup in the apparatus and the flash point tested before the next sample, until all samples were tested.

### *2.2. Experimental procedures*

### *2.2.1 Flash point test*

This test was carried out using Pensky-Martens flash point apparatus (IP, 1982). The cup in the apparatus was cleaned with xylene, rinsed with acetone, and dried. 100ml of the pure bitumen with average penetration of 45pen was transferred into the cup and mixed with 1ml to 10ml in steps of 1ml of each lighter petroleum product at a time. The cup was fixed into position in the apparatus, assembled with a thermometer, and heated at a uniform rate. The temperature on the thermometer at which the vapour first flashes with a blue flame was recorded as the flash point of the bitumen blend. After each test, the cup was washed and dried before the next test, which was carried out for all samples of the blended bitumen and the unblended (pure) bitumen.

### *2.2.2 Penetration test*

This test was carried out with the standard penetrometer apparatus in accordance with ASTM standard (ASTM, 1978 (D5-52)), where the material was first heated to a temperature of about 120$^0$C. However, some bitumen/kerosene mixtures whose flash points are well below 120$^0$C as obtained experimentally (see Table A1) will result in fire hazards if heated to this temperature. Such bitumen/kerosene mixtures and those whose flash points are close to or equal to 120$^0$C were first heated to temperatures below their flash points, while other bitumen/kerosene mixtures with flash points greater than 120$^0$C and bitumen/diesel and bitumen/lubricating oil mixtures were first heated to a temperature of about 120$^0$C. The hot liquid mixture was stirred thoroughly, poured into a small tin-cup, and allowed to cool in air. The tin-cup with the material inside it was then transferred to a water-bath maintained at 25$^o$C (using ice block) for 1 to 1½ hours. (The temperature of the cold water-bath was greater than the recommended 25$^0$C at the time of the experiment). Thereafter, the tin-cup with the material was removed from the water-bath and placed on the penetrometer table. A needle was passed vertically through the surface of the bitumen mixture for five seconds under a load of 100g and the value of penetration read from the penetrometer dial and recorded accordingly. This procedure was carried out for 30 samples of the various bitumen blends (i.e. 10 samples for each diluent) as well as the pure bitumen.

### *2.2.3 Viscosity test*

Bitumen/kerosene blends were first heated as indicated in the preceding section, while bitumen/diesel and bitumen/lubricating oil blends were first heated to a temperature of about 120$^o$C in accordance with ASTM standard (ASTM, 1978 (D88-53)). The liquid mixture was then poured into a viscometer cup in the standard tar viscometer apparatus, and stirred thoroughly to ensure uniform temperature throughout the mixture. The liquid was allowed to flow by lifting the closing ball valve of the apparatus, and the time (in seconds) taken for the liquid to reach a 50ml mark of a 100ml receiver beaker was recorded using a stop-watch. This procedure was carried out for all samples of the bitumen blends including the pure bitumen. (Note that for bitumem/diesel and bitumen/lubricating oil blends, the temperature of the mixture dropped to 110°C after stirring, so the viscous flow time of each sample was measured at this temperature. The viscous flow time for bitumen/kerosene blends whose flash points are greater than 120°C were measured at 110°C, while the viscous flow time for bitumen/kerosene blends with flash point less than 120°C were measured at the flash point of each blend).

## 3. RESULTS AND DISCUSSION

Table 1 shows measured properties of the unblended low penetration-grade bitumen, while those of the various bitumen blends are presented in Table A1 (see Appendix A).

**Table 1:** Measured properties of unblended bitumen

| Properties | Value |
|---|---|
| Penetration at 25°C | 45pen |
| Viscous flow time at about 110°C | 4.3s |
| Flash point | 230°C |

Results of Tables 1 and A1 are shown graphically in Figs. 1-3, where it may be seen that kerosene has a more pronounced effect on the measured properties of the blended bitumen, followed by diesel, with lubricating oil exhibiting the least effect. Kerosene, diesel, and lubricating oil, lower the flash point of the pure bitumen and the degree of reduction in the flash point increases as the volume of each diluent in the blended bitumen increases. This is obvious for bitumen/kerosene and bitumen/diesel blends, but the volume of lubricating oil does not have significant effect on the flash point of its mixture with the pure bitumen (see Fig. 1).

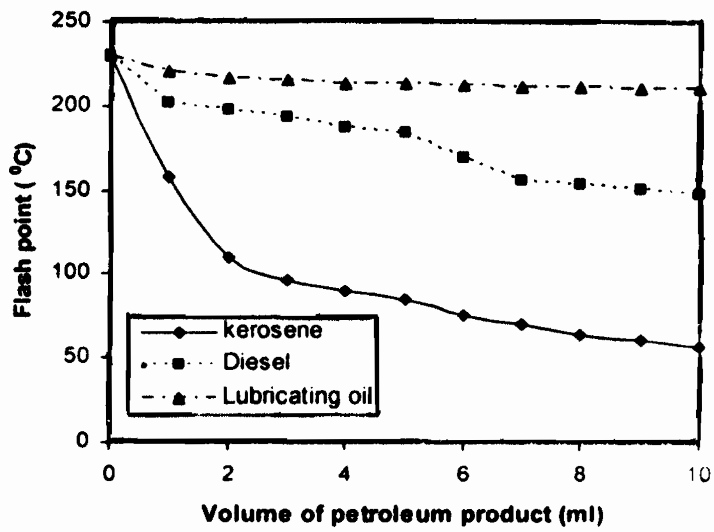


**Fig. 1**: Flash point of bitumen blends.

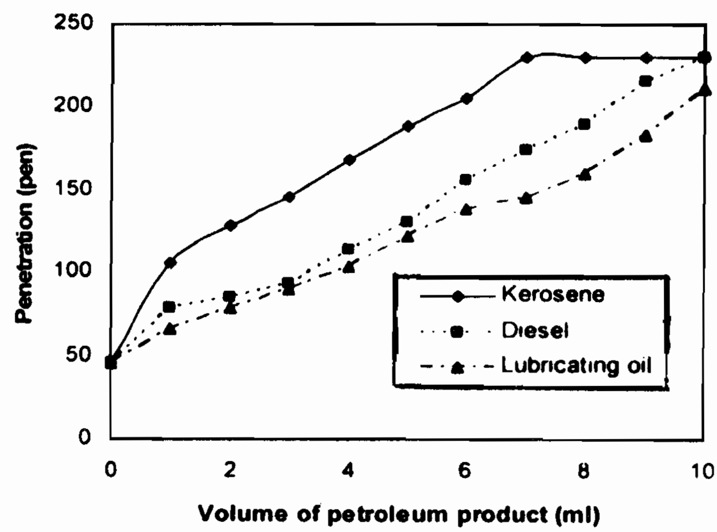


**Fig. 2**: Penetration of bitumen blends.

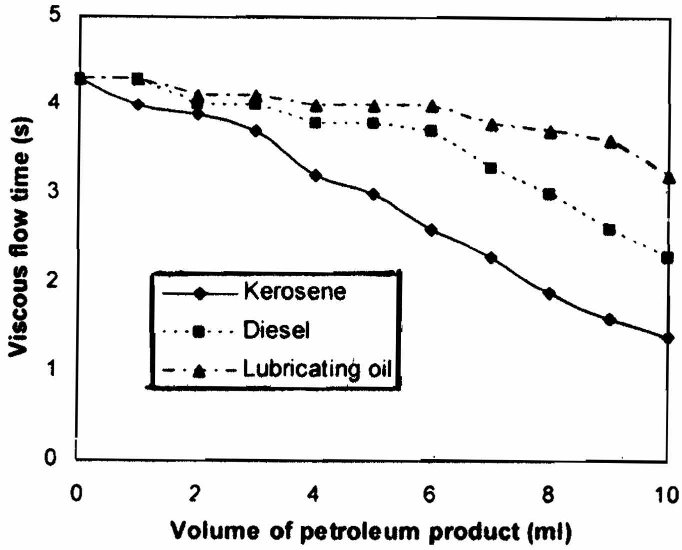


**Fig. 3:** Viscosity of bitumen blends in terms of viscous flow time.

It is evident from Fig. 2 that the penetration of each bitumen/diluent mixture increases as the volume of diluent in the mixture increases. At a given volume of the diluents, bitumen/kerosene mixture gives the highest penetration value, followed by bitumen/diesel mixture, with the least penetration value by bitumen/lubricating oil mixture. This can be attributable to the fact that kerosene is less viscous than diesel, and diesel less viscous than lubricating oil. Figure 3 indicates that the viscous flow time of bitumen/diluent mixture decreases as the volume of diluent increases, which is expected. The viscous flow time at a given volume of diluent is smallest for bitumen/kerosene blend, larger for bitumen/diesel blend, and largest for bitumen/lubricating oil blend, which is consistent with Fig. 2. It may be seen by comparing Figs. 2 and 3 that the penetration of bitumen/diluent mixture is related to its viscosity; that is, the penetration of blended bitumen increases as its viscosity (or viscous flow time) decreases. The maximum or minimum volume of diluent to be added to pure bitumen may depend on the required penetration and/or flash point of the blend. For example, Table 2 shows the volume of diluent in blended bitumen with a penetration of 150pen, and the corresponding viscous flow time and flash point of the blend, as estimated from Figs. 1-3.

**Table 2**: Parameters of bitumen/diluent mixture with penetration of 150pen.

| Property | Diluent | | |
|---|---|---|---|
| | Kerosene | Diesel | Lubricating oil |
| Volume per 100ml of pure bitumen (ml) | 3.27 | 5.73 | 7.28 |
| Viscous flow time (s) | 3.58 | 3.65 | 3.52 |
| Flash point ($^0$C) | 94.12 | 172.55 | 209.8 |

It may be observed from Table 2 that the viscous flow time of the three bitumen blends are very close, indicating that the viscosities of the different blends with the same penetration are approximately equal.

Bitumen/kerosene blend is liquid enough to penetrate into treated surface which when cold (if applied in a hot state) turns into harder asphalt and plug capillary voids in the soil (Oglesby and Hicks, 1982). The range of flash point of medium-curing cutback bitumen (i.e. 50$^0$C - 99$^0$C (O'Flaherty, 2002)) indicates that bitumen/kerosene blend designed for priming during road surfacing may be applied without heating and can be heated to a temperature of about 50$^0$C without the risk of fire. The high flash points of bitumen/diesel and bitumen/lubricating oil mixtures in Table A1 indicate that these bitumen blends are slow-curing and very-slow-curing respectively and not suitable for road surfacing (Oglesby and Hicks, 1982). Thus, the range of flash point of medium-curing cutback bitumen most appropriate for road priming is from 50$^0$C to 99$^0$C. The corresponding range of volume of kerosene in medium-curing cutback bitumen is about 10ml-2.5ml per 100ml of pure bitumen with penetration of 45pen (see Table A1).

## 4. CONCLUSION

An experimental study on the flash point, viscosity, and penetration of low penetration-grade bitumen blended with kerosene, diesel, and lubricating oil has been presented. Addition of diluent increases the penetration of bitumen, but lowers its viscosity and flashpoint. These effects are more pronounced with kerosene as the diluent, followed by diesel, and then lubricating oil. The volume of each diluent used in the analysis varies from 1ml to 10ml in steps of 1ml per 100ml of pure bitumen and the corresponding ranges of flash point of the various bitumen blends are 158$^0$C-56$^0$C for kerosene, 202$^0$C-148$^0$C for diesel, and 221$^0$C-210$^0$C for lubricating oil; the corresponding ranges of penetration of the bitumen blends are 105pen-230pen for kerosene, 78pen-230pen for diesel, and 66pen-212pen for lubricating oil; the corresponding ranges of viscous flow time are 4.0s-1.4s for kerosene, 4.3s-2.3s for diesel, and 4.3s-3.2s for lubricating oil. It is shown that kerosene is the best of the three diluents considered in the analysis for preparing blended bitumen for priming during road surfacing. The range of flash point of medium-curing cutback bitumen most appropriate for road priming is 50$^0$C - 99$^0$C.

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# Appendix A

**Table A1:** Measured properties of bitumen/diluent mixtures.

| Volume of diluent (ml) | Penetration at 25°C (Pen) | | | Viscous flow time (s) | | | Flash point (°C) | | |
|---|---|---|---|---|---|---|---|---|---|
| | kerosene | Diesel | Lubricating oil | kerosene | Diesel | Lubricating oil | kerosene | Diesel | Lubricating oil |
| 1 | 105 | 78 | 66 | 4.0 | 4.3 | 4.3 | 158 | 202 | 221 |
| 2 | 128 | 85 | 78 | 3.9 | 4.0 | 4.1 | 110 | 198 | 217 |
| 3 | 146 | 93 | 90 | 3.7 | 4.0 | 4.1 | 96 | 193 | 215 |
| 4 | 168 | 114 | 103 | 3.2 | 3.8 | 4.0 | 90 | 187 | 213 |
| 5 | 189 | 130 | 122 | 3.0 | 3.8 | 4.0 | 85 | 184 | 213 |
| 6 | 206 | 156 | 138 | 2.6 | 3.7 | 4.0 | 75 | 169 | 212 |
| 7 | 230 | 175 | 146 | 2.3 | 3.3 | 3.8 | 70 | 156 | 211 |
| 8 | 230 | 190 | 160 | 1.9 | 3.0 | 3.7 | 64 | 154 | 211 |
| 9 | 230 | 216 | 184 | 1.6 | 2.6 | 3.6 | 61 | 151 | 210 |
| 10 | 230 | 230 | 212 | 1.4 | 2.3 | 3.2 | 56 | 148 | 210 |