IN-SITU AND LABORATORY DETERMINATION OF THERMAL PROPERTIES OF TAR SANDS IN EASTERN DAHOMEY BASIN SOUTHWESTERN NIGERIA

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ABSTRACT

In bitumen recovery from tar sand where heat transfer takes place through injection of thermal energy into the tar sand formation, it is of great importance to estimate the thermal properties of such tar sand. The aims of this research is to determine the thermal properties of tar sand in the Eastern Dahomey basin, Nigeria with a view to having more information in planning for thermal recovery of the tar sand.

Twelve locations were established along the tar sand belt in order to measure its thermal properties. The thermal properties of the tar sand were measured in-situ using KD2 Pro thermal analyzer. In laboratory, thermal properties of samples from each location were measured and their physical properties that influenced them (such as grain size distribution, percentage by weight of bitumen content, moisture content, bulk density, porosity and dry density of the samples) were determined. Thermal conductivity, specific heat and bulk density were used to calculate the thermal effusivity of the tar sands.

Positive correlations were observed between the values of the field and laboratory measurements of thermal resistivity, thermal conductivity, thermal diffusivity, thermal effusivity and volumetric specific heat with R-values 0.86, 0.85, 0.81, 0.78 and 0.49 respectively. It was observed that the thermal properties of the tar sand determined have close similarities with those reported on Athabasca tar sand of Canada. This implies that the thermal recovery process used in the Athabasca basin could also be employed in the Eastern Dahomey basin, Nigeria.

Keywords: *Thermal conductivity, Thermal diffusivity, Volumetric specific heat, Tar sands, Thermal Recovery, Eastern Dahomey basin*.

1. INTRODUCTION

As the world is becoming more and more energy conscious, much research has been done in devising the optimum means to tap the vast hydrocarbon reserves buried underneath the earth crust. The recovery method for conventional light oil is relatively simple compared to the methods used for recovering heavy oil, which is highly viscous and immobile under ambient reservoirs' conditions. To enhance the mobility of the heavy hydrocarbon, thermal recovery methods are generally used. Reservoir temperature and pressure conditions may be drastically altered during the thermal recovery process. Among many variables that characterize the reservoir are the thermal properties of the hydrocarbon deposit and its adjacent formations (Scott and Seto, 1986). Properties of tar sand such as thermal conductivity and thermal diffusivity have usually been measured on disturbed core material under ambient laboratory conditions and the measured values are not representative of field conditions at in-situ thermally stimulated production facilities. The major factors that control the thermal properties of the tar sand are the types of mineral grains, the soil structure and its density (Scott and Seto, 1986). As recognized by many investigators, such as Cervenan *et al* (1981) the degree of fluid saturation plays significant role in determining the thermal properties of a material. Therefore, thermal properties of tar sand are of paramount importance in the design of commercial recovery operation that involves heating of the tar sand as well as in the research activities that preceded field applications.

Considerable efforts have been made in the past to develop techniques to determine important thermal properties; namely, conductivity (K), diffusivity (α), and specific heat capacity (c) under field and laboratory conditions. This led to investigations of the thermal properties of rocks and soils using various methods such as the steady-state divided-bar technique, Beck, 1976, needle-probe method, Von Herzen and Maxwell, 1959, quick thermal conductivity meter, Ito *et al*, 1977, and several other transient, steady-state, and modulated methods, Morabito, 1989.

Recently, Decagon Devices Inc. has developed the *KD2*-Pro meter logger with two specific sensors: the small dual-needle sensor SH-1, use to measure the thermal properties which employs the dual needle heat pulse (DNHP) method, and KS-1 thermal sensor that is a single needle which employs an infinite line heat source (ILHS) method. In order to obtain reliable data, field and laboratory procedures to determine thermal properties with the *KD2*-Pro need to be normalized, according to existing standards and manufacturer's indications. The present work describes the step towards the development of a field and laboratory procedure to obtain reliable, accurate, and rapid thermal properties dataset in tar sand taking into account the current accepted standard.

1.1 Study Location and Accessibility

The study area covers part of Ondo and Ogun states, Southwestern Nigeria. It is located within longitudes 04º00'00"E and 05º00'00"E and latitudes 06º15'00"N and 07º00'00". The major roads in the area are the Lagos-Ore-Benin road that runs from the Western part of the area to the eastern part and the Ondo-Ore-Okitipupa road that runs from the Northern part of the map and terminates at Igbokoda. The study area from east to west spans across settlements like Gbeleju Loda, Agbabu, Ilubirin, Yegbata, Legbeda in Igorisha Camp, Lonto in Ladawo camp, Mobolade, Idiopopo, Idobilayo, Gbegude, Paranta and Iwopin

1.2 Drainage Pattern and Geology of the Study Area

The area is generally well drained such that there are presence of streams and rivers that flow southward. Some rivers in the area are perennial while some, and the streams are seasonal and got dried up during the dry season. Most of the rivers and their tributaries are flanked by relatively wide flood plains which have varying width and occurrence of wide valley floors are common and almost all of these are ill-drained and swampy especially during the rainy season.

The tar sand belt of Southwestern Nigeria falls within the Eastern Dahomey (Benin) Basin which straddles the basement-sediment contact (Figure 1). In geologic terms, the tarbelt straddles the Ilesha Spur or Okitipupa High, a structural and slight topographic divide. To the west are plains and uplands of the Benin Basin; to the east are the valley and delta of the Niger River system that is developed above the subsurface Anambra Basin.

The stratigraphic column by Ministry of Solid Minerals Development Nigeria (2004) identifies three divisions of the Nigeria bitumen deposit; Araromi (Abeokuta formation), Afowo and the Ise formations in that order. The ages are Maastrichtian, Campanian-Aptian and Barremian- Neocomian respectively in the cretaceous period. Two main horizons generally referred to in reports as Horizon X and Y which have been encountered within depths of 100m, along latitude $6^0$36'N.

Upper Bituminous Sediments - Horizon X has thickness ranges between 9m and 22m, comprising varying lithofacies: coarse to medium to fine-grained sandstone with interbeds of sandy clays, (1-2m thick).

Lower Bituminous Sediments Horizon Y has thickness varying from 3m eastwards to about 23m westwards.

2. MATERIALS AND METHODS

The thermal properties of the tar sand was determined using a *KD2* Pro (Plate 1) that complies fully with ASTM D5334-08, IEEE 442 - 1981, and SSSA Standards. It is a portable, hand held field and laboratory thermal properties analyzer that measures both the solid and fluid media thermal properties using transient heated needle. This technique applied a heat pulse to the needle, and with time, the response in temperature is monitored during and after the heat pulse at an adjacent needle or the heated needle.

To determine the thermal diffusivity and specific heat, a small dual-needle sensor (SH-1) was employed (Decagon Devices Inc.). This kind of sensor uses the method of heat pulse that yield reliable soil thermal diffusivity (α) and volumetric specific heat capacity (C) which uses non-linear least square procedure for estimation during both processes. However, thermal admittance/effusivity was calculated as

$$\boldsymbol{Thermal\ Effusivity} = \sqrt{\boldsymbol{Thermal\ Conductivity}(\boldsymbol{\lambda}) \times \boldsymbol{Heat\ Capacity}(\boldsymbol{\rho C})}$$

$$\boldsymbol{Thermal\ Effusivity} = \sqrt{(\boldsymbol{\lambda \rho C})}$$

2.1 Field Procedure

The first step to develop a procedure to measure the thermal properties of tar sand begins with the location of the seepages, exposure of the fresh tar sand surface and field sampling design.

2.2 In Situ Measurements

The measurement include the location of the tar sand (as seepages in farmlands, exposures along road cuts, cliff faces, river sources, and river channels), verification and preparation of the thermal sensor (calibration) using standard glycerol in order to check whether it was functioning properly (Krishanaiah, 2003) was done. The thermal sensor to be used was then selected (TR-1 and SH-1). The exposed surface of the tar sand was then scrapped to established a fresh surface that has not being oxidized. The needle was positioned with respect to the fresh surface established and then inserted into the tar sand. Thermal properties were then measured by using the appropriate sensor TR-1and SH-1.

Using KD2 Pro to take measurement, appropriate sensor was chosen and attached to the KD2 Pro meter, then the meter was turned on. The sensor was properly inserted into the tar sand. After the measurement, the instrument is allowed to rest for 25 minutes before taking the next reading for TR-1 and 15 minutes for SH-1 for equilibrum position to be established. Masurements were taken at twelve different locations along the tar sands belt.

2.3 Collection of Samples

Samples were collected for laboratory analyses. Twelve samples were collected at different locations along the tar belt from east at Loda (location 1) to west at Iwopin (location 12). The samples were taken in polythene bags and stored in cool and dry place before the necessary tests were carried out on them.

2.4 Analytical Laboratory Procedure

The samples were packed into a box of 1cm by 1cm and were allowed to settle so that it will form a square shape. The box loaded with samples were kept in polythene bag and were stored in a cool and dry place for two weeks. After two weeks, the samples were removed from the boxes and their thermal properties were measured following the same procedure as it was done in the field. To characterize the tar sands of eastern Dahomey Basin, variables such as, grain size distribution, dry density, specific gravity, percentage by weight of bitumen content, porosity, and moisture content, were determined in the laboratory.

Mechanical or sieve analysis was used for the grain size analysis after the tar sand has been soaked in kerosine for twenty-four hours to remove the bitumen content. A pycnometer bottle was used to determine the specific gravity while the porosity was determined using volumetric flask of known volume.

3.0 Results And Discussion

3.1 Thermal Properties

3.1.1 Thermal Resistivity

The thermal resistivity of the tar sand in the study area (Table 1) ranges from 63.01- 362.4°C-cm/W with a mean of 153.13 °C-cm/W for field measurement and 81.17 - 296.9°C-cm/W with a mean of 143.32 °C-cm/W for laboratory measurement. It is clearly shown in Figure 2 that there are variations in the thermal resistivity values measured for the twelve locations which could be attributed to the difference in physical properties of the tar sand at each location. The high values in locations 2, 4, 10 and 11 could be attributed to the increase in the percentage by weight of bitumen saturation as result of high porosity due to decrease in the particle sizes of the sand that housed the bitumen. The values of the thermal resistivity of the tar sand in the study locations has a close relationship with the values of thermal resistivity values of tar sand of Athabasca oil sands, Kern River oil sands and Asphalt ridge oil sand in Canada which were calculated from the values of the thermal conductivity that were measured by Clarke (1944), and Lindberg *et al* (1985).

3.1.2 Thermal Conductivity

The thermal conductivity values in the study locations (Table 1) ranges from 0.276 – 1.587W/mK with an average of 0.983 W/mK for the field measurement while the laboratory measurements ranges in values from 0.337 – 1.252W/mK with an average of 0.861 W/mK. Figure 3 showed the variations in the values of the thermal conductivity of the tar sand in the study locations. They clearly showed the reverse of the thermal resistivity. The thermal conductivity of the tar sand of the Eastern Dahomey, Nigeria have close values with those measured on Athabasca oil sand by Clarke (1944), Kern River oil sand by Somerton *et al* (1974) and Asphalt oil Ridge by Lindberg *et al* (1985). Also, it has a close values with those determined by Cervenan (1981) and Rajeshwar *et al* (1982) from Athabasca oil sand.

3.1.3 Thermal Diffusivity

The thermal diffusivity values in the study area (Table 1) ranges from 0.170 – 0.774mm²/s with average of 0.516 mm^2/s for the field measurements, while the laboratory values ranged between 0.206 – 0.817mm²/s with average of $0.443mm^2/s$. It can be observed from Figure 4 that the thermal diffusivity of the study locations varies from one another. There was significant drop in values of thermal diffusivity at locations 2,4,10 and 11 which could be attributed to the same reason that caused the decrease in the value of the thermal conductivity at these locations. The thermal diffusivity value of the tar sand measured in Eastern Dahomey Basin, Nigeria has close agreement with that of Athabasca oil sand, Canada measured by Scott and Seto (1986).

3.1.4 Volumetric Specific Heat

The values of the volumetric specific heat measured at each locations (Table 1) in the field ranges from 0.873 – 3.143mJ/m³K with an average of 1.877mJ/m³K and the measurement in the laboratory have their values ranging from 1.381 – 2.44mJ/m³K with an average of 1.936mJ/m³K. Since the major constituents of the tar sand in the study locations are quartz and the tar, the quartz could be said to have influenced the specific heat values obtained. The specific heat of bitumen ranges from 1.85 – 3.9 mJ/m³K (Lindberg *et al*, 1985) and that of quartz is 0.170 – 0.190 mJ/m³K which is much lower. This showed that the specific heat (Figure 5) in the study location is being influenced by the bitumen saturation rather than the quartz constituents. The volumetric specific heat values of the tar sand measured in Eastern Dahomey Basin, Nigeria had close agreement with that of Athabasca oil sands, Canada measured by Cervenan *et al*, (1981) and Scott and Seto (1986).

3.1.5 Thermal Effusivity

Thermal admittance of tar sand in the study area for field and laboratory measurements is given in Table 2. Thermal admittance or effusivity in the study locations for field measuremets ranges from 0.598 – 2.412 $Jm^{-2}K^{-1}S^{-½}$ with a mean of 1.711 $Jm^{-2}K^{-1}S^{-½}$ while the laboratory measurement ranges from 0.877 – 2.293 $Jm^{-2}K^{-1}S^{-½}$ with a mean of 1.658 $Jm^{-2}K^{-1}S^{-½}$. Figures 6 displayed the distribution of the thermal effusivity measured in the field and that measured in the laboratory. The figure showed that there were much variations in the thermal admittance of the tar sand in the locations studied. Acccording to Oyekan and Kamiyo (2011), materials with high thermal effusivity cannot hold heat long enough because heat will quickly dissipitate from its surface as soon as surrounding temperature drops. On the other hand, materials with low thermal effussivity will hold heat much longer. From the figures, locations 2, 4,10 and 11 have lower thermal admittance compare to other locations and, based on Oyekan and Kamiyo(2011) findings, they will hold heat much longer than tar sand of other loctions.

3.2 Correlating Field and Laboratory Data

The comparisons and variation in the value of thermal properties for both field and laboratory measurements are shown in Figures 7a to f, where it can be seen that the values of field thermal resistivity, thermal conductivity, thermal diffusivity, thermal effusivity, volumetric specific heat and temperature and those measured in the laboratory have no significant variation from each other. They correlate positively with R-values of 0.68, 0.85, 0.81, 0.78, 0.49 and 0.73 respectively which shows that the values got from the field and the laboratory fit excellently except the volumetric specific heat that has weak correlation. This showed that the result of the measurement made is consistent and that the physical properties that impact much on the thermal properties are not being affected much in moving the sample to the laboratory from the field.

3.3 Variation of Thermal Properties with Physical Properties of Tar Sands

Table 3. showed the results of the determined physical properties of the tar sands in the study locations

3.3.1 Percentage by Weight of Bitumen Content

The percentage by weight of bitumen content in the study locations ranges from 11.88 to 41.50% with an average of 31.02 %. Figure 8a and b showed negative correlation exists between thermal conductivity and percentage by weight of bitumen content. This is in agreement with Somerton *et al* (1974), Cervenan *et al*, (1981) and Scott and Seto (1986). Also in Figures 8c and d, there is a negative correlation between thermal diffusivity and percentage by weight of bitumen content as reported in literatures (Scott and Seto, 1986).

3.3.2 Moisture Content

The moisture contents of tar sand in the study locations range from 0.24 to 0.44% with an average of 0.32 %. In Figures 9a and b, a negative correlation exists between thermal resistivity and moisture content and also in Figures 9c and d; there is positive correlation between moisture content and thermal conductivity and diffusivity. This agrees with the work of past researchers such as Cervenan *et al* (1981), Scott and Seto (1986), IEEE (1998) and Ramakrishnan, (2012).

3.3.3 Dry Density

The dry density in the study area ranges from 1202 to 2201Kg/m^3 with a mean of 1629.25Kg/m^3. This result gives rise to negative correlation between thermal resistivity and specific heat and dry density, so an increase in the dry density will cause reduction in thermal resistivity value. The general trend as depicted in Figures 10a to d where positive correlation exist between the dry density and thermal conductivity and thermal diffusivity respectively which agrees with the work of Somerton *et al* (1974), Cervenan *et al*, (1981) and Scott and Seto (1986).

3.3.4 Porosity

The porosity of the tar sand which is shown in Table 2, was observed to affect its thermal properties as shown in Figures 11a to d. Porosity of the tar sand varies from 19.5% to 32.8% with a mean of 27.2%. Figures 11a and b showed positive correlation with R-value for the field measurement to be 0.81 and that of laboratory to be 0.70. The variation of thermal resistivity with porosity was observed to agree with those reported in previous works (Tomar, 1999; Krishnaiah *et al*, 2004).

Thermal conductivity drops steadily with gradual increase in porosity which is consistent with previous experimental investigations (Usowicz et al, 1996). In oil bearing formations, thermal conductivity plays important role as it is used to indicate porosity of the formations (Zierfuss and Van der Vliet, 1956). Also, the negative correlation between porosity and thermal diffusivity means increase in porosity will give rise to decrease in thermal diffusivity which agrees with experimental investigation of Somerton *et al* (1974), Cervenan *et al* (1981) and Scott and Seto (1986) on tar sands and Krishnaiah *et al* (2004) on soil. However, the relationship between porosity and specific heat did not agree with reports in literatures that an increase in specific heat will lead to increase in porosity but as observed in Figure 11c and d, it agrees with the work of Oladunjoye and Sanuade (2012b).

3.3.5 Temperature

The temperature in the study locations ranged from 24.59 to 31.84^{0}C with an average of 26.23^{0}C for the field measurements while it ranged from 23.12 to 27.82^{0}C with a mean of 25.29^{0}C for laboratory measurements. The variation in the temperature across the studied locations is shown in Figure 12. The thermal resistivity measured in the laboratory with weak positive correlation (R= 0.44) agrees with observation of IEEE (1998), and Paasschens *et al* (2004) but the field measurements with negative correlation (R= -0.03) differ from this. The drop in thermal conductivity of tar sand in the studied locations with respect to increase in temperature (Figure 12a and b) was in agreement with the observation of Somerton (1973) on tar sand and Dubow *et al* (1978) on oil shale. Thermal diffusivity was found to decrease with increasing temperature with negative correlation value of -0.099 and -0.55 for field and laboratory measurements respectively. It appears to certain extent, that the higher the bitumen saturation of a location, the higher the percentage drops in diffusivity value with increasing temperature. The field temperature has a negative correlation (R=-0.064) while the laboratory measurement gave positive correlation (R=0.102). The field measurement do not agrees with Hans-Dieter and Rudiger (2003); who stated that specific heat increases with temperature.

3.3.6 Grain size

The percentage of medium grained sand (Table 4 and Figure 13) is higher compare to other particle sizes. This is why there is increase in the thermal resistivity value in all the locations (Brandon and Mitchell, 1998) because grain size distribution and shape of a soil determine its density, porosity and the pore size distribution and these properties in turn directly affects the tar sand's thermal resistivity. The particle size distributions affect the manner in which the bitumen and moisture are being held.

Thermal conductivity drops when the grain is smaller that is why thermal conductivity here is moderate because the grains are not too coarse or too fine.

4. SUMMARY AND CONCLUSIONS

4.1 Summary

The thermal properties of tar sand at eastern Dahomey Basin were determined both in-situ and in laboratory. From the research carried out, it was discovered that thermal diffusivity and thermal conductivity decrease with increase in temperature and to certain extent; the more saturated the tar sand with bitumen, the higher the percentage decrease in thermal diffusivity and conductivity. It was also observed from the research that thermal resistivity of tar sand was found to increase with increase in porosity while it decreases with increase in dry density. It was observed in the research that with increase in the bitumen saturation of the tar sand, the thermal diffusivity and conductivity were found to decrease. A high dry density value of the tar sand, result in the high thermal diffusivity and conductivity value while a high porosity results in drops in the values of the two thermal properties. The specific heat increases with increase in bitumen saturation while it decreases with increase the dry density and porosity.

4.2 Conclusions

The most important of the thermal properties in the thermal recovery process of tar sands are the thermal conductivity and the specific heat because they help in calculating the cost of generating electrical energy that will produce the quantity of heat needed for the recovery of bitumen from the tar sand. Therefore, the thermal properties of tar sand are of paramount importance in the design of commercial recovery operation that involves heating of the tar sand as well as in the research activities that preceded field applications.

It has been observed that the thermal properties of the tar sand in the study locations and the variation with their physical properties matched well with the results reported in literature except their variation with thermal resistivity. It can be concluded that, from the thermal properties and the physical properties determined and correlated, the tar sand in Eastern Dahomey basin; Nigeria has close thermal properties as well as physical properties to that of Athabasca oil sand in Canada. Therefore the thermal recovery process used in the Athabasca basin could also be employed in recovering tar sand of Eastern Dahomey basin, Nigeria.

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Table I: Thermal Properties of Tar Sands in the Afowo Formation of the Eastern Dahomey Basin, Southwestern Nigeria

Locations Name and Numbers	Thermal Resistivity (°C-cm/W)		Thermal Conductivity (W/°C-cm)		Thermal Diffusivity (mm^2/s)		Volumetric specific Heat (mJ/m^3K)		Temperature (°C)	
	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab
Loda (1)	63.01	97.25	1.587	1.030	0.780	0.508	2.034	1.716	25.87	23.12
Agbabu (2)	304.1	296.9	0.328	0.337	0.176	0.222	1.859	1.518	26.17	26.38
Ilubirin (3)	66.16	134.4	1.511	0.748	0.481	0.348	3.143	2.170	26.69	26.75
Yegbata (4)	259.5	264.1	0.357	0.390	0.170	0.206	2.269	1.890	25.55	25.89
Legbeda (5)	101.0	104.8	0.990	0.977	0.622	0.627	1.591	1.660	25.46	24.94
Lonto (6)	79.97	81.17	1.250	1.232	0.715	0.817	1.749	1.599	25.67	24.42
Mobolade (7)	78.99	85.33	1.266	1.185	0.586	0.487	2.160	2.440	25.72	25.13
Idiopopo (8)	70.05	81.84	1.427	1.252	0.741	0.506	1.928	2.400	25.29	24.35
Idiobilayo (9)	64.92	83.96	1.540	1.200	0.774	0.520	1.989	2.310	24.59	24.03
Gbegude (10)	277.1	179.6	0.361	0.565	0.290	0.311	1.244	1.829	25.12	25.03
Paranta (11)	362.4	197.6	0.276	0.518	0.316	0.373	0.873	1.381	26.79	25.64
Iwopin (12)	110.3	112.9	0.907	0.893	0.537	0.385	1.690	2.322	31.84	27.82

Table II: Thermal Admittance/Effusivity of the Tar Sands in the study Locations

Locations	Density,ρ(Kg/m^3)	Thermal conductivity,K (W/Mk)		Volumetric Specific Heat, C (mJ/m^3K)		Therma Effusivity, β ($Jm^{-2}K^{-1}S^{-½}$)	
		Field	Lab	Field	Lab	Field	Lab
1	1803.00	1.587	1.030	2.034	1.716	2.412	1.785
2	1502.00	0.328	0.337	1.859	1.518	0.957	0.877
3	1225.00	1.511	0.748	3.143	2.170	2.411	1.410
4	1502.00	0.357	0.390	2.269	1.890	1.103	1.052
5	2017.50	0.990	0.977	1.591	1.660	1.782	1.809
6	2206.90	1.250	1.232	1.749	1.599	2.197	2.085
7	1566.50	1.266	1.185	2.160	2.440	2.070	2.129
8	1750.00	1.427	1.252	1.928	2.400	2.194	2.293
9	1704.50	1.540	1.200	1.989	2.310	2.285	2.174
10	1782.50	0.361	0.565	1.244	1.829	0.895	1.357
11	1486.00	0.276	0.518	0.873	1.381	0.598	1.031
12	1728.00	0.907	0.893	1.690	2.322	1.627	1.893

Table III: Phyical Properties of Tar Sands in the study locations

Locations	Percentage by Weight of bitumen content (%)	Dry Density (Kg/m^3)	Porosity (%)	Moisture content (%)	Specific Gravity
1	28.070	1797	19.50	0.390	1.8725
2	41.499	1125	32.50	0.240	1.7557
3	39.536	1221	24.15	0.270	1.8700
4	37.100	1202	30.40	0.250	1.5189
5	18.610	2011	28.35	0.410	2.0750
6	11.878	2201	25.40	0.440	2.2715
7	34.699	1563	26.25	0.300	1.8410
8	30.828	1746	27.55	0.330	1.8250
9	33.242	1700	22.40	0.310	1.7665
10	29.080	1777	28.90	0.340	1.8535
11	35.688	1480	32.80	0.285	1.4750
12	31.992	1728	28.65	0.320	1.7650

Table IV: Summary of the grain size distribution of the tar sands of the study locations

Locations	**Gravel (%)**	**Coarse Sand (%)**	**Medium Sand (%)**	**Fine Sand (%)**
LI	0.10	16.4	61.9	21.6
L2	0.00	11.80	63.60	24.60
L3	0.14	17.56	63.5	18.8
L4	0.20	15.6	65.6	18.6
L5	1.10	32.2	51.1	15.6
L6	1.40	23.2	58.2	17.2
L7	1.20	28.2	55.6	15.0
L8	0.20	27.1	57.8	14.9
L9	0.20	9.80	64.9	25.1
L10	3.50	28.4	46.6	9.50
L11	1.40	32.2	49.9	16.5
L12	1.20	31.7	49.4	17.7

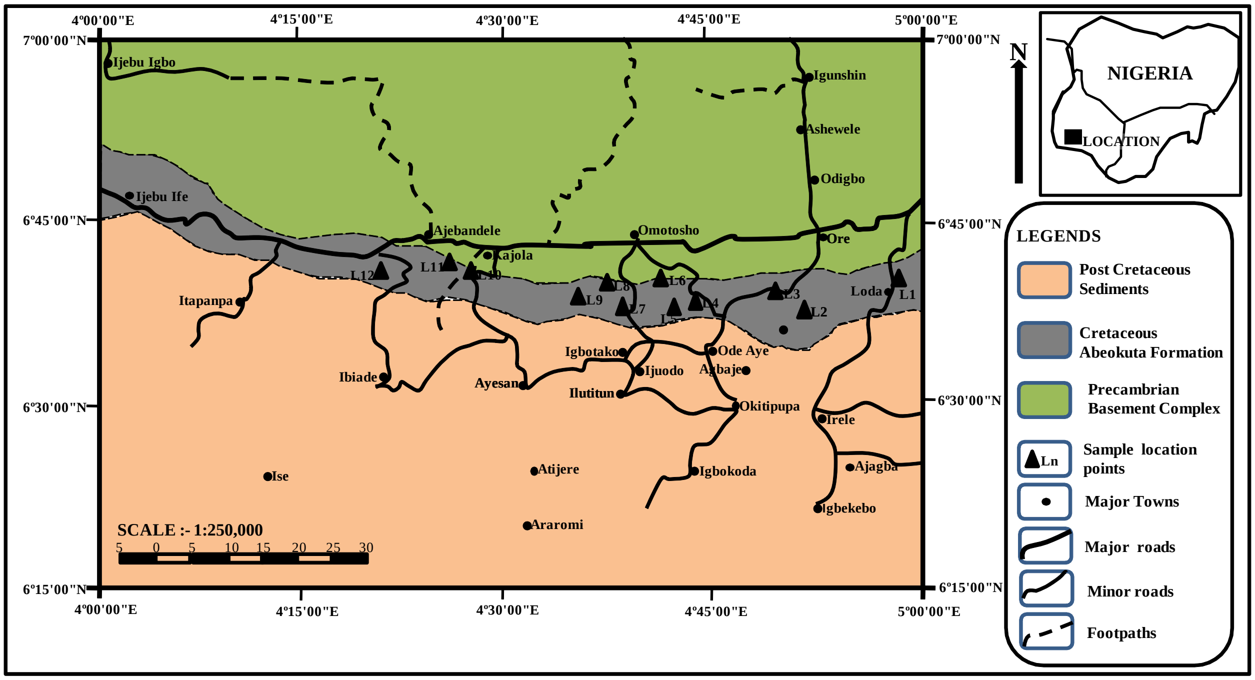

Figure 1: Geological Map of Southwestern Nigeria, Showing the tar sand belt and the studied locations (Modified after Enu, 1985)

(1)

(2)

Plate 1: A KD2 Pro Meter

Plate 2: Measurement of the thermal properties

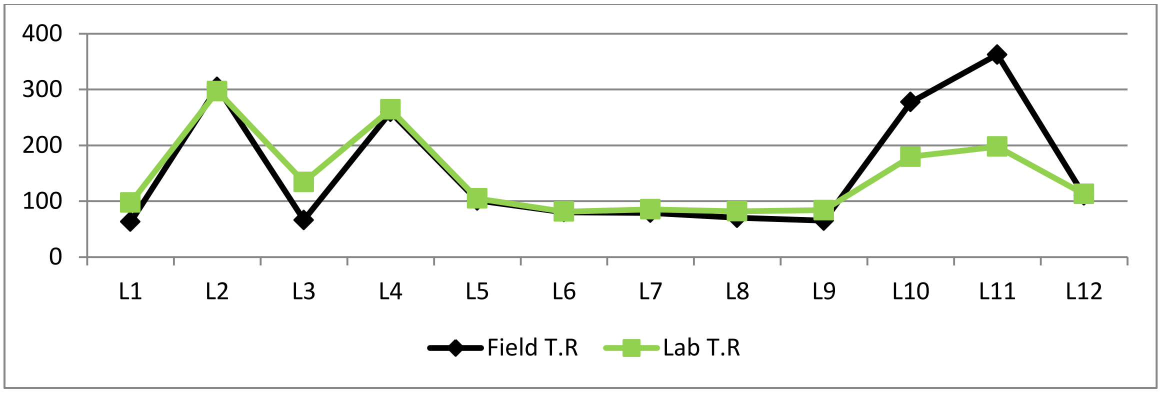

Figure 2: Variation in the field and laboratory measurement of thermal resistivity of the Tar Sands in the study Locations

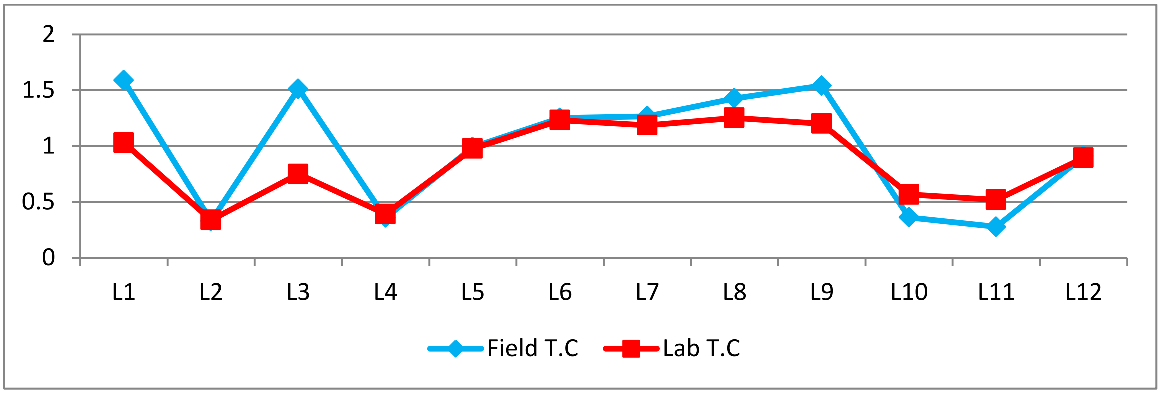

Figure 3: Variation in the field and laboratory measurement of thermal conductivity of the Tar Sands in the study Locations

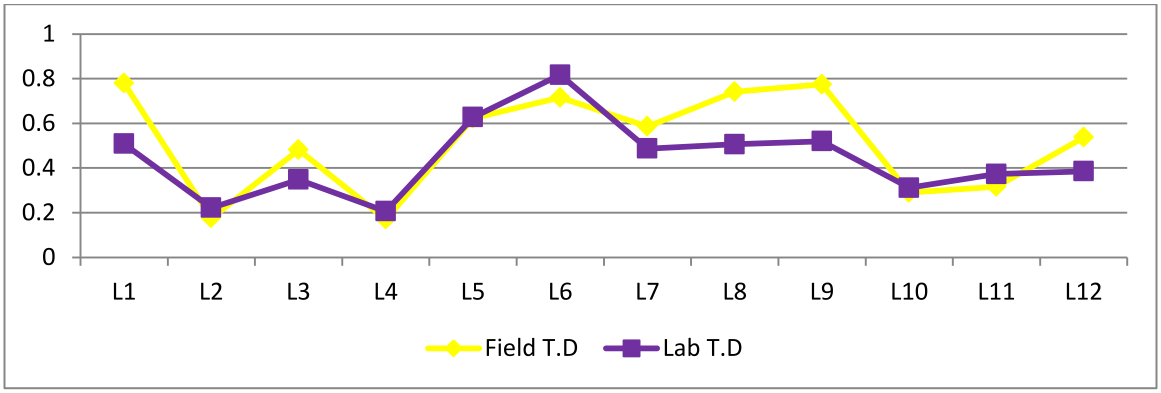

Figure 4: Variation in the field and laboratory measurement of thermal diffusivity of the Tar Sands in the study Locations

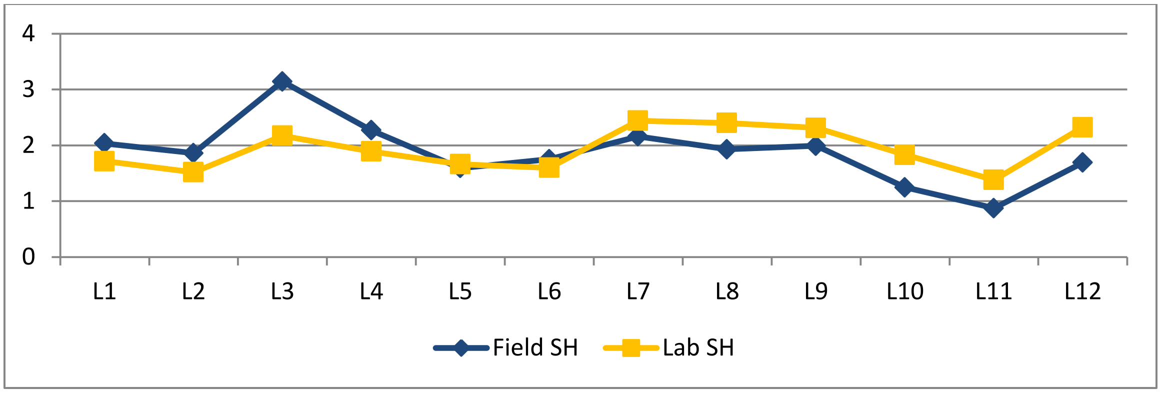

Figure 5: Variation in the field and laboratory measurement of volumetric specific heat of the Tar Sands in the study Locations

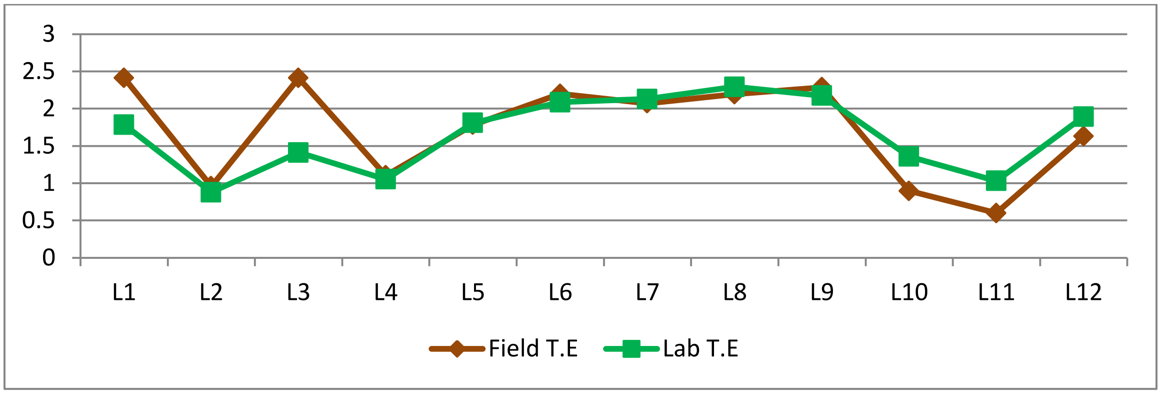

Figure 6a and b: Variation in the field and laboratory measurement of thermal effusivity of the Tar Sands in the study Locations

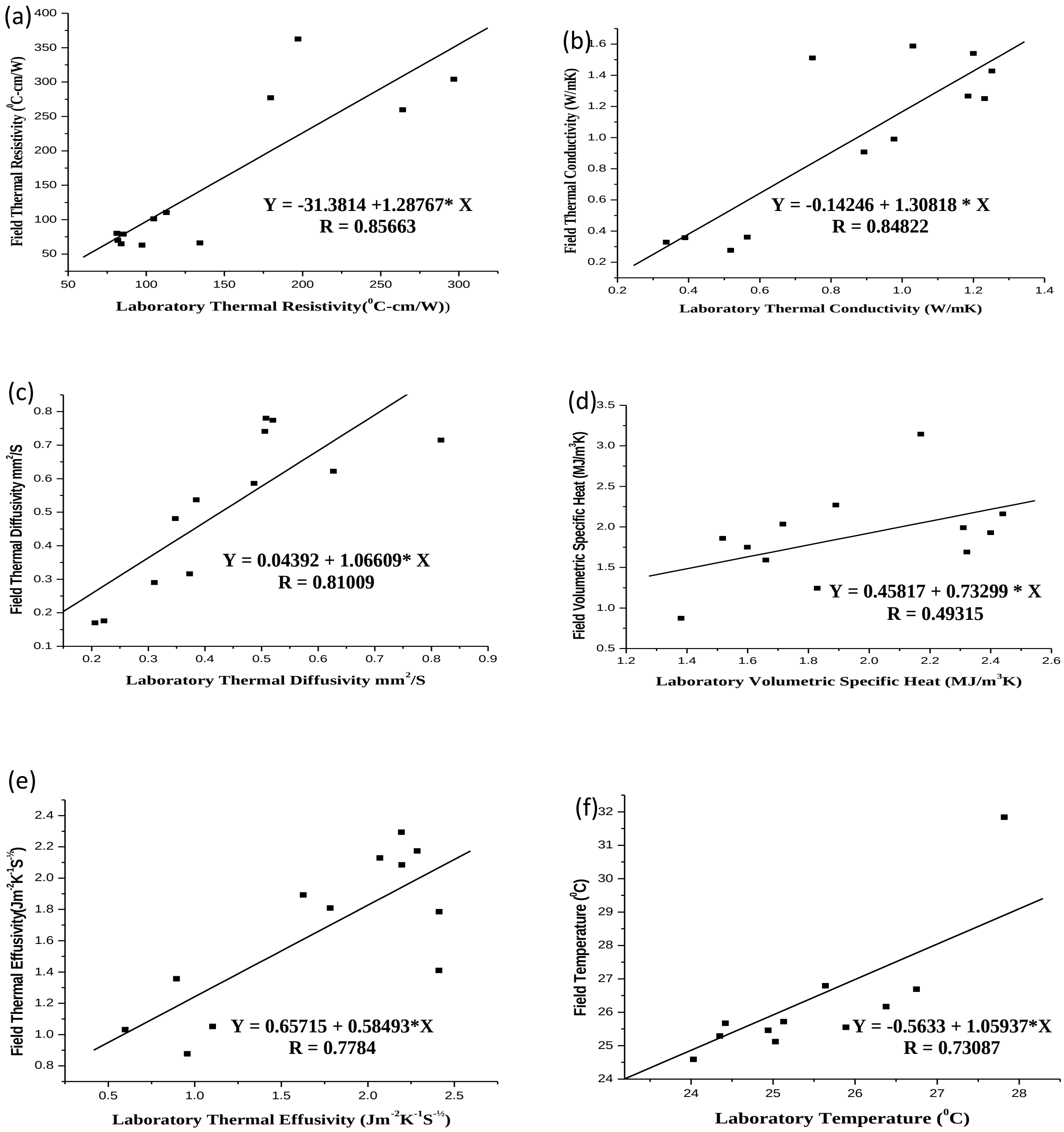

Figure 7: Variation in values of field and laboratory measured thermal properties of tar sand

(a) Thermal Resistivity (b) Thermal Conductivity (c) Thermal Diffusivity
(d) Volumetric Specific Heat (e) Thermal Effusivity (f) Temperature

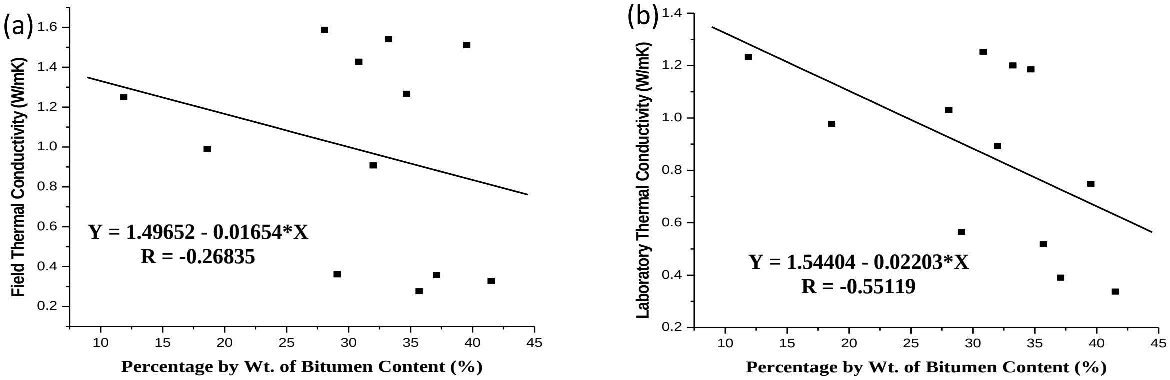

Figure 8a and b: Variation of Field and Laboratory Thermal Conductivity with Percentage by weight of Bitumen Content

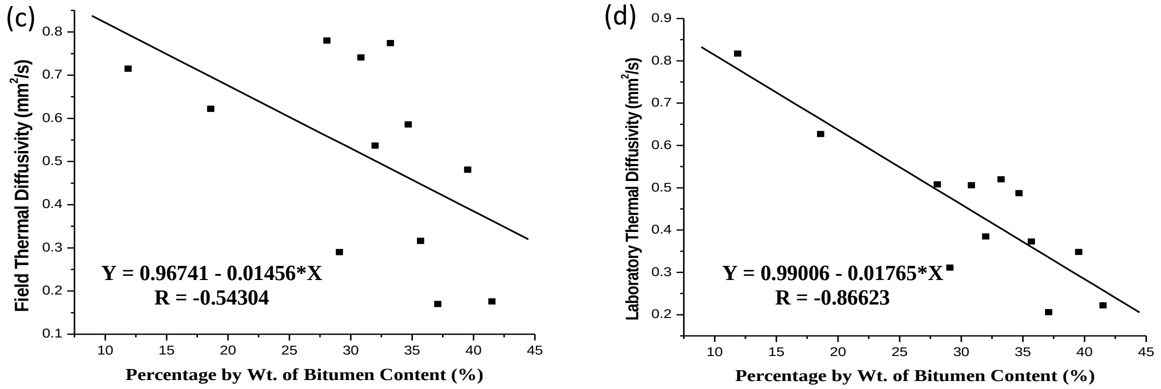

Figure 8c and d: Variation of Field and Laboratory Thermal Diffusivity with Percentage by weight of Bitumen Content

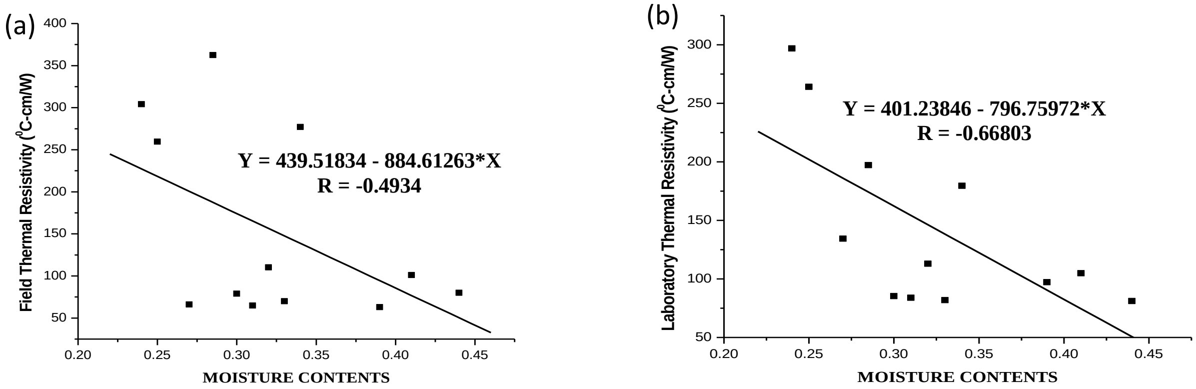

Figure 9a and b: Variation of field and laboratory Thermal Resistivity with moisture content

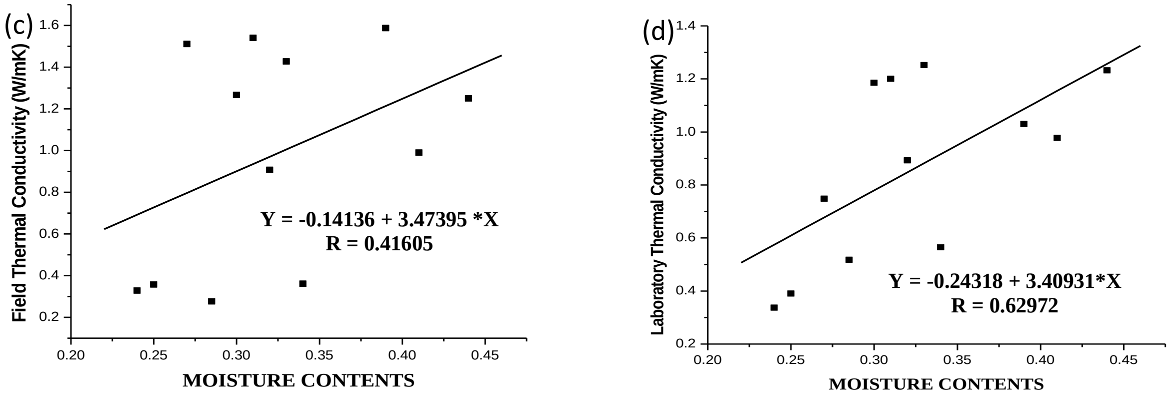

Figure 9c and d: Variation of field and laboratory Thermal Conductivity with moisture content

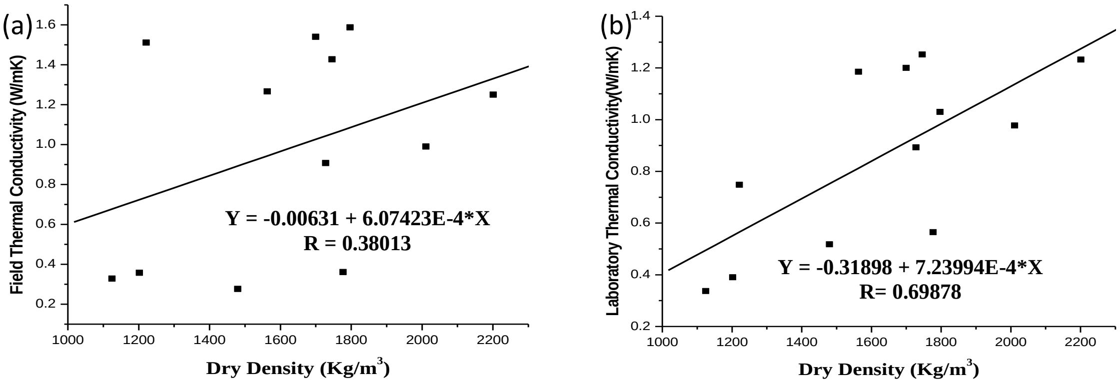

Figure 10a and b: Variation of Field and Laboratory Thermal Conductivity with Dry Den

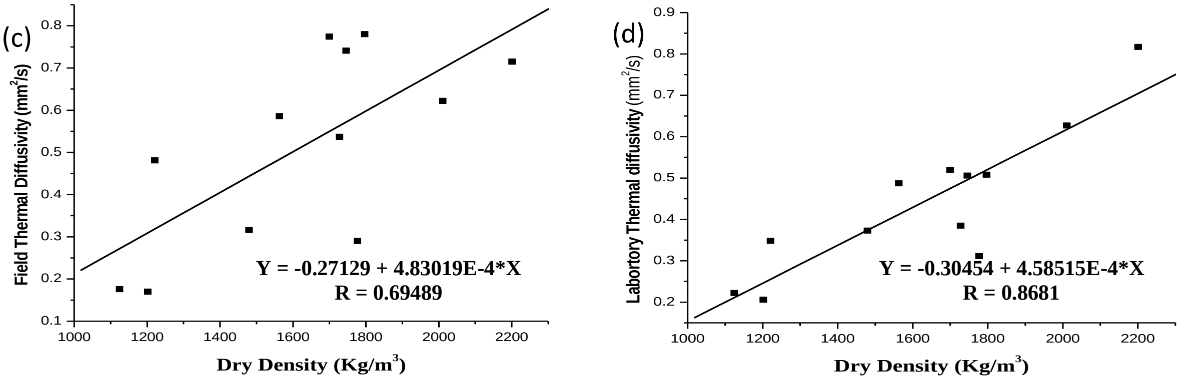

Figure 10c and d: Variation of Field and Laboratory Thermal Diffusivity with Dry De

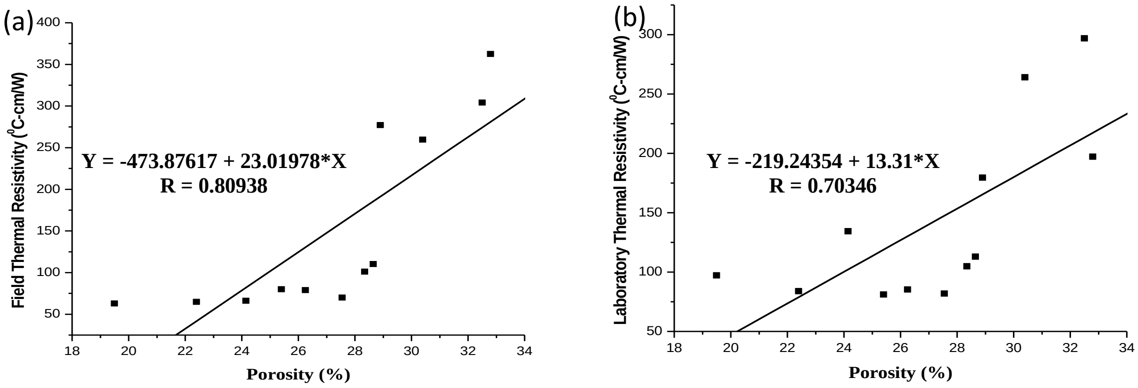

Figure 11a and b: Variation of field and laboratory Thermal Resistivity with Porosity

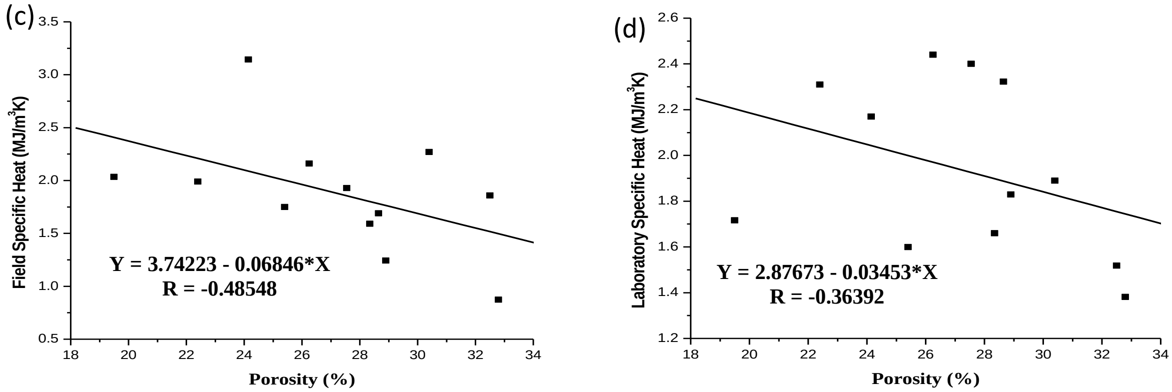

Figure 11c and d: Variation of field and laboratory Specific Heat with Porosity

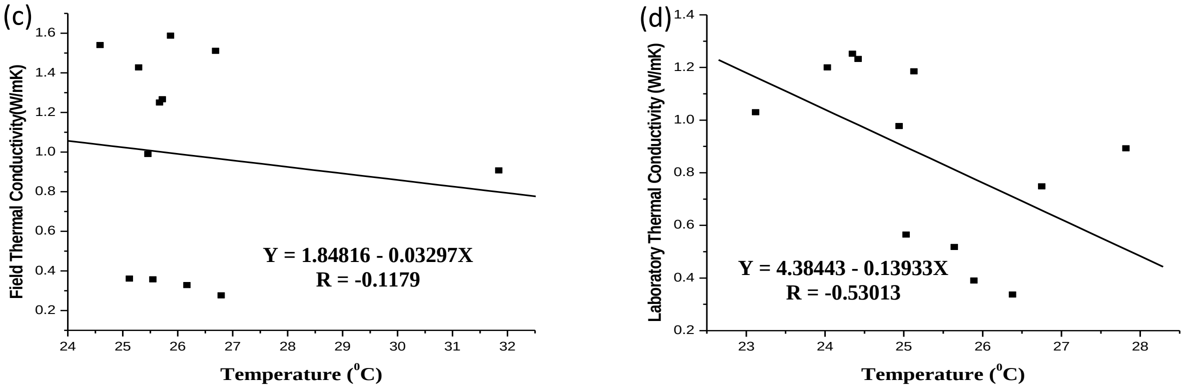

Figure 12a and b: Variation of field and laboratory Thermal Conductivity with Temperature

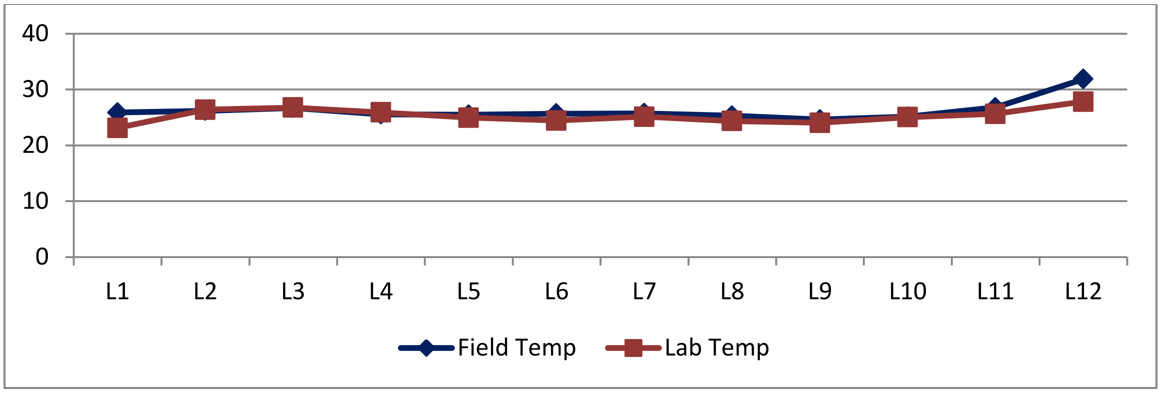

Figure 12: Variation in the field and laboratory measurement of Temperaure of the Tar Sands in the study Location

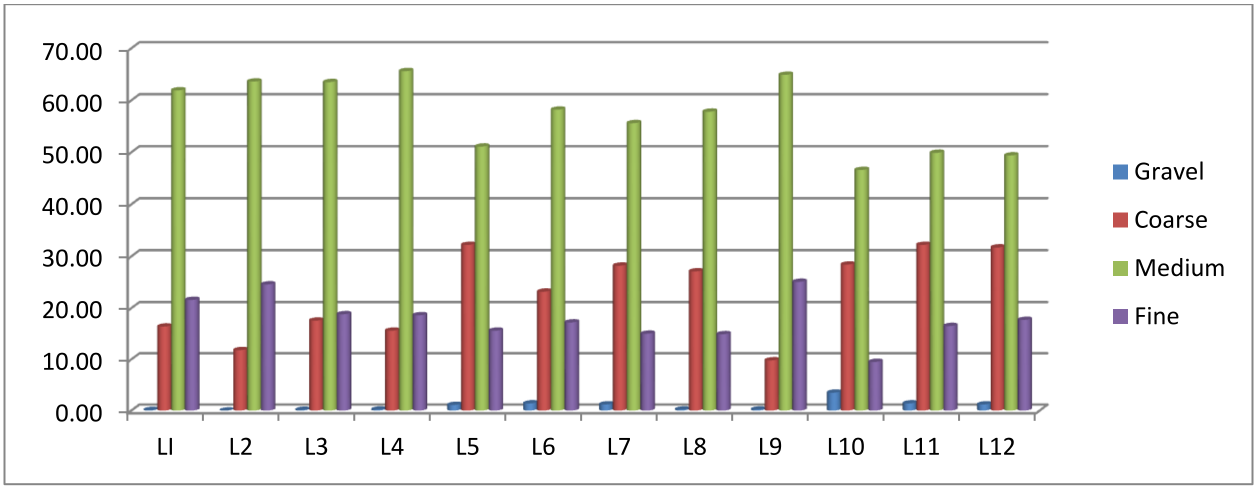

Figure 13: Bar chart showing grain size distribution of the study locations.