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Improvement of Thermal Resistivity of Desert Sand for Use in High Voltage Cable Beddings and Foundation in Arid Zones

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IMPROVEMENT OF THERMAL RESISTIVITY OF DESERT SAND FOR USE IN HIGH VOLTAGE CABLE BEDDINGS AND FOUNDATION IN ARID ZONES

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ABSTRACT

The soil thermal resistivity is of a great importance for the design of high voltage cables. Underground cables generate heat as a result of power losses when transmitting current. This heat must be dissipated in a form that will not affect the performance of the cables. The presence of moisture normally helps to reduce the thermal resistivity and keeps it within the design range. In arid areas the moisture content is decreased to very low values in dry seasons. This is found to bring the thermal resistively beyond the design ranges. Major cable failures took place during summer times in Riyadh city and surroundings. This was noted to increase for some years before 2002, which reported high temperature and generally hot climate. The Saudi Electric Company requested AMNK to investigate the possible ways to improve the thermal properties of backfill material used in bedding. In this research, improvement of the thermal resistivety (reduction) is obtained by adding cement and moisture and then dehydrating the mixture. The optimum amount of cement content to suite the Saudi desert material was found 5% after studying two common sand types using a non-steady state probe TP-02 with CR 10 X thermal program. The Saudi Electric Company found the process very successful and used it as part of the specifications and requirements in cable construction procedures.

INTRODUCTION

The need for the study of thermal resistivity of soils and building materials is of great importance in engineering practice. The rate at which the substances can conduct heat is a property used to evaluate the suitability of the material for a specific use. This paper deals with the thermal properties of the bedding material used to support high voltage underground cables. The Saudi electric company noticed frequent failures of underground cable in summer times in Riyadh and other hot areas of the country. Investigations of these failures yielded no clear reasons for such accidents except for the unknown assumed thermal parameters for the bedding sand and soils surrounding the cables. Initial investigations reported values in excess of design values. Almuhandis Nizar Kurdi Consulting Engineers (AMNK) was requested by the Saudi Electric Company to perform investigations on the thermal parameters of sand used in bedding and cable trenches. It was also required to investigate the possible ways of controlling and improving the local sands such that design values remain valid even in extreme dry and hot weather conditions. This paper reflects the efforts made to study the thermal resistivity of local sand available to contractors and suggested a method of treatment so as to keep most of the available material within specific design ranges.

GENERAL THEORY

The study of unidirectional conduction of heat transfer is expressed by Fourier simple equation:

$$q = -kA \frac{d\theta}{dx} \qquad (1)$$

where :
q = the rate of heat along x axis
A= cross –sectional area
$d\theta / dx$ = the temperature gradient.
K = the thermal conductivity of the material.

Thermal needles or probes simulate a line source of heat input in a homogenous medium. After a short period of time the temperature rise is found function of the heater power, and the medium thermal conductivity. This could be stated mathematically as:

$$\frac{\delta \theta}{\delta t} = \alpha \left(\frac{\delta^2 \theta}{\delta r^2} + \frac{1}{r} \frac{\delta \theta}{\delta r} \right) \qquad (2)$$

Applying boundary conditions the above equation can be solved to give the following relationship:

$$\Delta\theta = \frac{Q}{4 \pi k} \log_e \frac{t_2}{t_1} \qquad (3)$$

The plot of this equation will give a straight line with a slope equal to ($Q / 4 \pi k$). The thermal resistivity is equal to $1/k$.

CABLE BEDDING AND CASE BACKGROUND:

This case is related to a hot climate country where temperature close to 50 degrees Celsius is not uncommon.
With the exception of the province of Asir and few other areas Saudi Arabia is known of desert and semi-desert climate characterized by extreme heat during the day, and slight rainfall. This climate is not friendly with the cable bedding material used to support and protect high voltage underground cables. Major cable failures took place during

summer times in Riyadh city and surroundings. This was noted to increase for some years before 2002 where hot climate was reported. The study of the case was initiated by the Distribution Engineering Department, Planning Division during the year 2002. AMNK (Almuhandis Nizar Kurdi Consulting Engineers) was requested to perform studies on the thermal resistivity of the cable bedding material commonly used in Riyadh area and its surroundings. This publication presents the outcome of the research study

The carrying capacity of a cable is highly dependant on the resistance offered by the soil mass in dissipating the heat. The lesser the resistance to heat flow the higher the carrying capacity of cables.

The ambient and soil temperature in degrees Celsius for some selected regions in Saudi Arabia are given in table 1 below:

Table 1. Metrological data from selected parts of Saudi Arabia

Temp/ Region	Hofuf	Riyadh	Yanbu	Khurais
Monthly Normal Max Temp. (hottest month)	45	43	39	42
Monthly Normal Max Soil Temp. (1m below ground)	31	31	32	-
Highest recorded temperature	49	49	49	52

From Meteorological & Seismic data SAES-A-112.

A temperature of 53 ^{o}C was recorded for Shaybah in central region of Saudi Arabia. Aramco SAES-P-104 called for 60 ^{o}C design ambient temperature for exposed cables and 40 ^{o}C for buried cables soil temperature.

It was a routine practice in Saudi Arabia to assume some moisture when testing for soil resistivity in the order of 2 to 5% but this cannot be applicable to such dry and hot climate where moisture content below 0.5 % is common.

In this study a 100% dry conditions were assumed in measuring the thermal properties.

COMMON MATERIAL USED IN CABLE BEDDING

Considering the common design used in Saudi Arabia, ampacity and cable size are based on a thermal resistivity of 120 ^{o}C-cm/watt. This value is easily obtained in a wet climate for a wide variety of sand materials. This value cannot be attained for most of the poorly graded sand and dune sand of the Saudi deserts in the dry seasons. A high temperature of 80 to 90 ^{o}C close to cable and in overload and short-circuit conditions causes immediate drying to take place.

The sand material available within Riyadh is mostly poorly graded. Two types of sand are used.

1. Dune natural sand denoted as (S-1 and S-2). selected for this study. This material is sometimes described as red sand or wadi sand.
2. Sand material obtained from a crusher denoted as (S-3 and S4). This is white crushed sand poorly graded to well graded.

Other material used in this investigation in addition to the sand material included the ordinary Portland cement (Type I).

The following table presents the grain size distribution for the four samples of sand selected.

Table 2. Gradation of four samples of sands used in the study

	% < ¾ “	% < 3/8 “	% < No 4	% < No 10	% < No. 40	% < No. 100	% < No. 200	US-CS
S1	100	100	100	100	95	25.7	1.1	SP
S2	100	100	100	100	66.8	5.7	1.0	SP
S3	100	100	100	99.2	23	2.1	0.4	SP
S4	100	100	100	74.2	36.3	17.5	10	SW-SM

TESTING EQUIPMENT AND SAMPLE PREPARATION

In this study we utilized the thermal conductivity/resistivity set up established by Hukseflux Thermal Sensors (A Dutch Company). The system is known as TP 02 CR 10 X which consists of the following components:

- TP-02: A non-steady state probe. The internal parts of the needle include a heater element and a thermocouple.
- Power Supply: Regulated AC Power Supply capable of providing the required voltage and current.
- MCU: Measurement and control unit, including heat source and measurement units for current and voltage. Temperature monitor and digital readout device is also part of the MCU. Time readout unit is installed within the system.
- CR 10 X: This is a thermal program built in MCU
- PC 208 W: Software- user interface program.
- PC: Intel Pentium IV Computer 1.7 Gega processor.

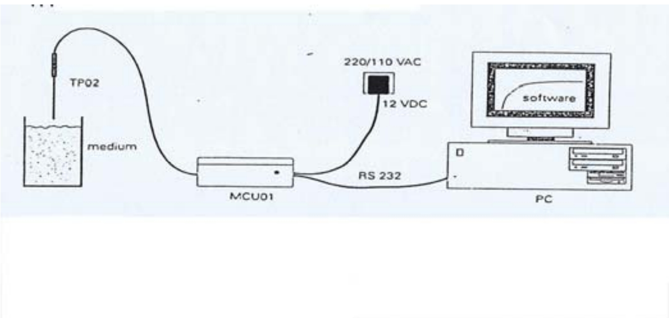


Figure 1. General overview for system used

In order to prepare a 100% dry sample, the sand is placed in 105 ^{o}C oven. This will remove all moisture. The density of the sand material is measured in two extreme states; minimum density and maximum density. Pouring the sand into a container of a known volume, then measuring the net weight of sand obtains the minimum density. The maximum density is obtained using a vibrating table commonly used for relative density test as per ASTM D 4253. A cylindrical mould made of steel 8.5 cm in diameter and 23.5 cm in height is used for testing the thermal properties of sand. In order to obtain the thermal resistivity the sand is placed in the mould and compacted by vibration to its maximum density. A hole is then drilled through the center of the sample to a depth of 15 cm. The diameter of the hole is kept below 0.6 cm. The thermal needle is then pushed into the hole. The thermal stability is observed through the computer monitor until equilibrium is attained and the sample is ready for testing.

The period of time for testing is selected at 600 seconds. Three different heating levels are available within the system. The computer program presents all the data at each second and performs computations and statistical analysis for the data.

The computer program computes the thermal resistivity at different time zones during the specified period. The average value is presented as the measured thermal resistivity. Standard deviation value is recorded.

This system is found to produce good repeatability in the range of 1 to 2%.

TESTING PROGRAM

At first the thermal resistivity at 0% moisture content is measured for the four sand samples selected for this study. The results are as follows:

Table 3 : Thermal resistivity of dry sand material.

Sand Reference	**Sample Type**	**Thermal Resistivity ^{o}C-cm/watt**
S1- (Nibras Elsharq)	Natural Sand	280
S2 (TDP)		268
S3 (Crushed poorly graded)	Crushed Sand	218
S4 (crushed well graded)		168

As can be observed from Table 3 none of the four sand samples can be used as a bedding material. In order to obtain 120 ^{o}C-cm/watt or less special treatment shall be considered.

The theory of improvement is based on introducing more sand grains and less air voids. This will help in reducing the resistant to heat transfer. Table 4 presents the thermal resistivity of material in connection with cable and cable design:

Table 4. Typical thermal resistivity for materials within trench

Sand Reference	**Thermal Resistivity ^{o}C-cm/watt**
Aluminum Conductor	0.45
Insulation Sheath	350
Concrete	90
Asphalt	1333
Water	165
Air	4000

Works of Sing & David (1999 and 2000) showed that the thermal resistivity in dry state for fine sand is varying from 260 to 360 ^{o}C-cm/watt and for coarse sand varies from 160 to 250 ^{o}C-cm/watt. They found that black cotton soils and fly ash could have thermal resistivity values as high as 1120 and 1100 ^{o}C-cm/watt respectively.

Al-Mana et al (1993) from the Research Institute, King Fahad University of Petrolium and Minerals performed a study on the thermal properties of the soil by suggesting different additives including cement, sandy silt, clay, limestone dust and fine limestone dust. They found out that 5% additive of cement to dune sand could reduce the thermal resistivity by 45%.

In this study we selected the cement as an additive. It is known that the use of concrete will give the most suitable thermal resistivity value that can dissipate heat from around the cable. The cost of concrete is rather high. Concrete ducts will add considerable construction cost and will cause time delay.

The program of this study included testing the sand types as dry and then with 5% moisture content with and without cement additive. Cement additives of 5% was considered and tested in dry state first and then with 5% moisture content followed by drying over 24 hours.

A new approach is considered for testing cement treated sand. It involved introducing moisture to sand cement mixture and then dehydrate the paste to a dry condition. .

The idea of wetting and dehydration is suggested to simulate site conditions when initial water within the soil is removed as a result of a dry weather or hot cables.

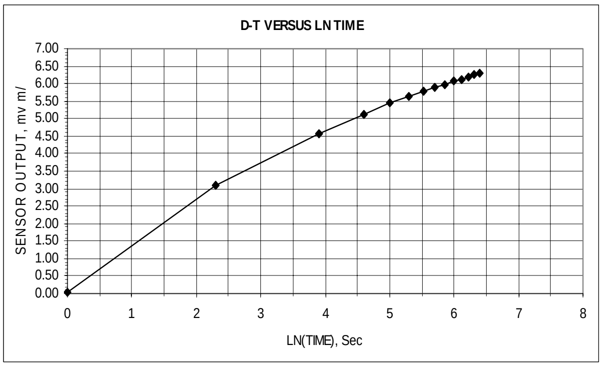
Sequence of testing is performed as follows:

1- Test the sand at 0% moisture content.
2- Test the sand at 5% moisture content

3- Test the sand with 5% cement at 0% moisture content.
4- Test the sand with 5% cement and 5% moisture content.
5- Test the sand with 5% cement and 5% moisture content dehydrated to zero moisture content.
6- Test sand with 5% moisture content dehydrated to zero moisture content.

TEST RESULTS

The thermal resistivity test results for each test are presented in a typical test data form as shown in Figure 2. Tables 5, 6, 7and 8 provides summary of the results.



Density	1.907	gm/cc
Moisture Content	0.0	%
Conductivity	0.357	W / m C
Thermal Resistivity	280	cm-C/W
Standard Diviation	0.800	
Heat	2.698	

Figure 2: Typical Test Data as worked out from tests

Table 5 Summary of tests carried out on S-1

Test condition description	**Cement content %**	**Moisture Content %**	**Thermal Resistivity °C-cm/watt**
Compacted dry sand	0	0	280
Compacted dry sand with cement	5	0	270
Compacted wet sand with cement	5	5	64
Compacted dehydrated sand with cement	5	5 dehydrated to zero	187

Table 6. Summary of tests carried out on S-2

Test condition description	**Cement content %**	**Moisture Content %**	**Thermal Resistivity °C-cm/watt**
Compacted dry sand	0	0	268
Compacted wet sand	0	5	70
Compacted dehydrated sand.	0	5 dehydrated to 0	255

Table 7. Summary of tests carried out on S-3

Test condition description	**Cement content %**	**Moisture Content %**	**Thermal Resistivity °C-cm/watt**
Compacted dry sand	0	0	218
Compacted wet sand	5	0	58
Compacted dehydrated sand.	0	5 dehydrated to 0	190
Compacted dry sand with cement	5	0	209
Compacted wet sand with cement	5	5	93
Compacted dehydrated sand with cement	5	5 dehydrated to zero	152

Table 8 Summary of tests on well graded crushed sand

Test condition description	**Cement content %**	**Moisture Content %**	**Thermal Resistivity °C-cm/watt**
Compacted dry sand	0	0	168
Compacted wet sand	0	5	*
Compacted dehydrated sand.	0	5 dehydrated to 0	*

* highly compacted penetration not enabled.

Resistivity tests from 17 localities from Riyadh and other surrounding districts are carried out by AMNK without treatments are as listed in Table 9:

Table 9: General information of untreated sand in the area.

Area or District	Sample Location	Classification	Thermal Resistivity °C-cm/watt
Riyadh	Dughum Cr	White sand SP	169
	Rab&Nas Cr	White sand SP	178
	Luhaidan Cr	White sand SP	173
	Thumama	Natural red sand SP	213
	Muzahmyah	Natural red sand SP	315
Qassim	AL Salihiya	Natural red sand SP	331
	Al Suhaima	Natural red sand SP	353
	East Sceco	Natural red sand SP	316
	Alswalimiah	Natural red sand SP	342
Kharj	Sahba Crus.	White sand SP	174
	Al rafaee	Natural red sand SP	340
	Al Hayathim	Natural red sand SP	328
Hail	Baga Road	Natural red sand SP	333
	Ring Road	Natural red sand SP	256
Dawad -mi	North Dawa	White- SW-SM	241
	West Dawa.	White- SW-SM	156
	East Dawa	White- SW-SM	181

Table 10. Test results of wadi natural sand treated using 5% cement for seven contractors.

Contractor Reference	Material description (Natural)	Thermal Resistivity °C-cm/watt	Mean Value
Rusais 1962	sand+5% cement	158	141
Sanbi 2752	sand+5% cement	141	
Tadam 2852	sand+5% cement	141	
Rosais 662	sand+5% cement	136	
Sanbi 1962	sand+5% cement	115	
Nebras 3052	sand+5% cement	164	
Rosais 1362	sand+5% cement	130	

Table 11. Test results of crushed white sand treated using 5% cement for twelve contractors are given table below:

Contractor Reference	Material description (Crushed white)	Thermal Resistivity °C-cm/watt	Mean Value
Meziad 22113	sand+5% cement	128	117
Nebras 1772	sand+5% cement	115	
Nebras 1102	sand+5% cement	125	
Nebras3052	sand+5% cement	112	
Nebrs 3052B	sand+5% cement	118	
Nebras 772	sand+5% cement	115	
Ojaimi 21122	sand+5% cement	118	
Ojaimi 172	sand+5% cement	101	
Rusais 262	sand+5% cement	130	
Tadam1982	sand+5% cement	111	
Tadam 1872	sand+5% cement	134	
Tadam 1962	sand+5% cement	103	

Results of cement treated sand in practice indicated a reduction of 40 to 50% .

DISCUSSION OF RESULTS

Most of the available sand in the area is poorly graded. Well graded sand was reported at few locations (Dawadmi area and crushers). The well graded material always give thermal resistivity lesser than the poorly graded. This is attributed to the excess amount of grains and less air voids within the soil mass.

The worst results for poorly graded sand were reported for areas of Qassim, Hail and AlKharj. The white crushed sand is always better than the natural sand due to fines created by crushing which is improving the gradation. Addition of dry cement without adding moisture is noted to give very slight reduction in the thermal resistivity.

Adding moisture to the sand cement mixture and then dehydrating was suggested for testing sand improved by cement. This method will eliminate false improvement offered by free water for the bedding material. Field measurements of thermal resistivity for material subjected to extreme drying may not be suitable for areas of hot climate where drying can bring the moisture content to zero percent. The laboratory testing assumed 100% dry condition will take place.

It can be seen from the results that the improvement using cement is confirmed for all natural sands (similar to S-1 and S-2) and all crushed sand (similar to S-3 and S-4). The reduction of thermal resistivity is on the order of 50% for the natural sand and 46% for the crushed white sand. The optimum amount of 5% is considered reliable. Increasing this amount will give more reduction in thermal resistivity but the bedding material will no longer be friable.
Some tests were carried out for 10% cement additions. Results are not shown in the tables but the thermal resitivity was brought down to less than 100 °C-cm/watt values viewing the outcome of this investigation SEC decided to apply certain procedures to reduce the thermal resistivity.

PROCEDURES RECOMMENDED BY SEC

The following diagrams and instructions to contractors were issued by the SEC. Based on the cable design and thermal properties of local material SEC Distribution Engineering Department put the following requirements for sand bedding in trenches involving one to more than four cables:

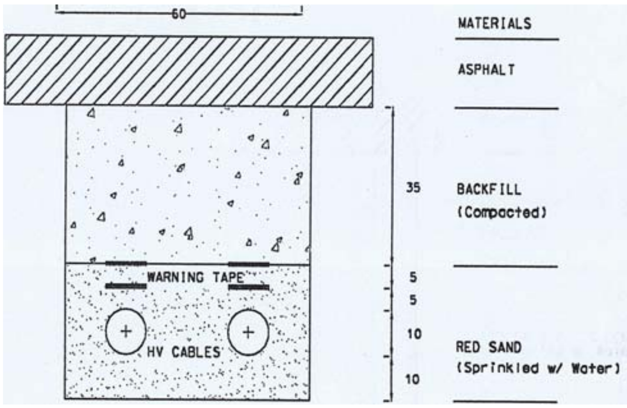


Fig 3 Details Measurements and Bedding Material for Trench with One or Two cables:

Case 1
Instructions:

- If the trench contains one or two cables, natural wadi sand can be used.
- Water of 10% need to be sprinkled on bedding material before warning tape is placed.

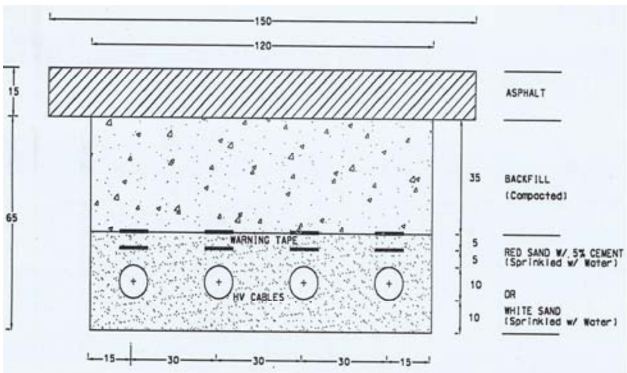


Fig 4. Details Measurements and Bedding Material for Trench with three or four cables:

Case II
Instructions:

- If the trench contains three or four cables, white crusher sand with sprinkled water or natural wadi sand with 5% cement can be used.
- Water of 10% need to be sprinkled on bedding material and before the warning tape is placed.
- Samples must be taken for testing to check reliability of mixing and the thermal resistivity.

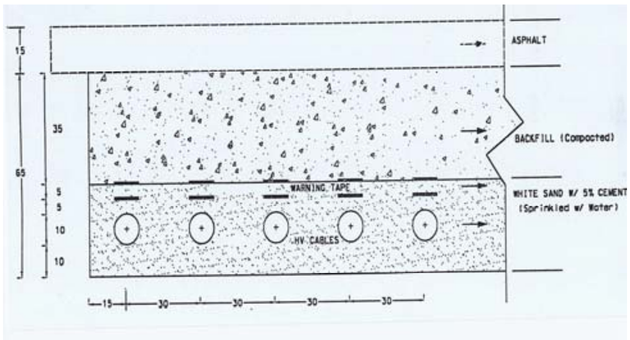


Fig 5. Details Measurements and Bedding Material for Trench with more than four cables:

Case III
Instructions:

- If the trench contains more than four cables, white crusher sand with sprinkled water shall be used.
- Water of 10% need to be sprinkled on bedding material and before the warning tape is placed.
- Samples must be taken for testing to check reliability of mixing and the thermal resistivity.

RECOMMENDATION AND CONCLUSIONS

The thermal resistivity of bedding material is a key factor in designing high voltage underground cable. Areas of hot weather shall be given special attention as drying of subsurface soils can cause the resistance to heat transfer to increase. The study of two types of sand in Riyadh and surrounding district indicated the presence of two main types of bedding sand; these are natural sand, which occurs in valleys and deserts, and white crushed sand, which obtained by crushing the sandstone or weakly cemented sand deposits. The investigation of these material indicated that the crushed sand gives a lower thermal resistivity than the natural desert sand.

Methods to improve the conductivity or reducing the thermal resistivity of material can be achieved by adding cement. The optimum amount which is not making the material stiff or hard is found to be 5% by weight of sand.
Moistening and drying is found to improve the conductivity. This is likely caused by a fraction of water that becomes permanent within the soil structure.

Addition of fine material or making the material well graded will result in lower thermal resistivity values.

It is very essential to perform thermal resistivity tests for the bedding material for arid and semi-arid areas where drying can take place in hot seasons.

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