The effects of sand and pipes on the temperature distributions of the underground cable

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Abstract: With the proliferation of underground systems and technologies, the investigation of thermal fields in the soil has become a subject of great attention in the emerging technology of buried structures. In this work, the heat transfer mechanisms in underground cable installations have presented. This paper considers a system of the underground cable of 12/20 (24) kV single core cable with a copper conductor and XLPE insulation, located in three models were designated for the experiment, a cable was located in (sand, PVC pipe, and an aluminum pipe). Furthermore, its reviews the results were obtained from a laboratory model where a wooden box was used, and the cable was placed inside the box by burying the cable in three different designs and using the soil used in Iraq and obtained a good results and comparisons were made at each model.

Keywords: Underground cable, Depth of laying, Aluminum pipe, PVC pipe.

1. Introduction
Thermal phenomena shall be considered when designing the underground electricity network. Because of the cable insulation meltdown occurrence, the permissible operating temperature must not exceed (90 °C). So, the cable engineers design the underground cable system in such a way that the conductor temperature does not exceed the optimum operating temperature of cable (65 °C) [1].

The underground power cable system may operate at the maximum possible current of the conductor; Heat dispersion from the hot conductor to the surrounding soil plays the main role in the performance evaluation of the underground cable. The current carrying capacity (ampacity) essentially can be depended on the temperature of the conductor; when the current carrying capacity too high, the cable becalms overheat [2]. In [3] presented the thermal analysis of underground power cable when the cable directly buried in the bank or situated in a PVC pipe in the bank. Experimental investigation of the thermal behavior of a 15 KV-XLPE underground power cable under different loadings directly situated in sand presented in [4]. For electrical engineering, the measurement of conductor temperature of the cable is related to the temperature obtained by using sensor or thermocouple. Therefore, the studies from [5] to [10] used the sensor and thermocouple in the practical measurements of the temperature of cable surface, insulation, armor, etc.

Based on the performed literature survey, it may be concluded that many different methods have implemented to assess the thermal field of underground power cables. The associated physics is complex involving the moisture migration, thermal, and electrical processes. Therefore, still, the developments of alternative methods to analyze and assess the heat dissipation processes from the underground power cables to their external environment are necessary.
2. Model construction

This study presents a wooden box as shown in Figure (1) which was used, and the cable was placed inside the box by burying the cable in three different models were designated for the experiment:

❖ Cable is located in the sand (model 1).
❖ Cable is located in a PVC pipe surrounded by sand (model 2).
❖ Cable is located in an aluminum pipe surrounded by sand (model 3).

The cable configuration of all the above-remarked models was chosen to be a flat formation.

![Figure 1. The wooden box: (a) the actual scene; (b) diagram (in cm).](image)

3. Materials

The list of equipment and materials used in this experiment are listed as follows:

a. Wooden box.
b. 12/20 (24) kV XLPE insulated single core cable with copper conductor.

This study performs a thermal analysis of 12/20 (24) kV XLPE insulated singlecore cable with a copper conductor as shown in Figure (3). The Cable characteristics are shown in table (1).
Figure 3. Illustrates the construction of the cable: 1 - Stranded copper conductor. 2 - Inner semi-conductive layer. 3 - XLPE insulation. 4 - Outer semi-conductive layer. 5 - Semi-conductive tape. 6 - Copper wire screen. 7 - Polyester tape. 8 - PVC outer sheath.

Table 1. Cable characteristics

| Characteristic                                  | Value | Unit  |
|------------------------------------------------|-------|-------|
| Long of cable used                             | 1     | m     |
| Cross-section area of copper conductor         | 50    | mm²   |
| Overall diameter of cable                      | 26.5  | mm    |
| Conductor DC resistance at 20 °C               | 0.387 | Ω/km  |
| Operating inductance                           | 0.64  | mh/km |
| Operating capacity                             | 0.17  | µf/km |
| Permissible operating temperature              | 90    | °C    |
| Current carrying capacity in the ground        | 233   | A     |

c. Thermocouple type (k)

In this study, three thermocouple types (k) have been used to measure temperature. These thermocouples were installed in direct contact with the uppermost for (conductor, XLPE insulation, and in the PVC outer sheath). The representation of the location for each thermocouple is shown in Figure 4.

Figure 4. The location for each thermocouple in the cable: (a): diagram; (b) the actual scene.
d. UNI-T Thermometer: A thermometer was used to display the readings of each thermocouple.
e. MEGGER DDA-6001: In this study, DDA-6001 (MEGGER) was used to supply the cable with the current required to test it in all three models [11].
f. Soil and sand: in this study, it was used fine sand free from gravel and rock.
g. Aluminum pipe.
h. PVC pipe.
i. Concrete block.
j. Warning Tape.
k. Electrical tape.

4. **Choice of installation design**
   a. **Cable is located in the sand (model 1).**
   The study considers a system of 12/20 (24) kV XLPE insulated single core cable with a copper conductor. The burial depth of the cable measured from the reference level (80 cm below the ground). In this model, the cable direct buried in sand as shown in Figure 5.

![Figure 5](image)

**Figure 5.** The cable directly buried in the sand.

b. **Cable is located in a PVC pipe surrounded by sand (model 2).**
   In this model, the cable inside a plastic tube (PVC) has a diameter of (110 mm) and a thickness of wall (2.7 mm) and buried in the sand. Due to the stiffness and light weight of the cable, the PVC pipe was filled with wood to force the cable to stay at the bottom of the pipe. The pipe hole was closed on both sides using foam as shown in Figure 6.
c. *Cable is located in an aluminum pipe surrounded by sand (model 3).*

In this model, the cable inside the aluminum pipe with a diameter of (110 mm) and a wall thickness of (2.5 mm) and buried in the sand. Because of the stiffness and the light weight of the cable, aluminum pipe was filled with wood to force the cable to stay at the bottom of the pipe. The pipe hole was closed on both sides using foamas shown in Figure 7.

**Figure 6.** The cable inside a plastic pipe (PVC) pipe surrounded by sand.

**Figure 7.** The cable inside the aluminum pipe surrounded by sand.
5. Experimental Scheme:
The experiment schedule is given in Table (2).

| Model | Environment           | Test time (h) | Test current (A) |
|-------|-----------------------|---------------|-----------------|
| 1     | Direct buried in the sand | 5             | 200             |
| 2     | PVC pipe              | 5             | 200             |
| 3     | Aluminum pipe         | 5             | 200             |

Each experiment started without current being loaded at a steady temperature condition, and it is worth mentioning that the process of thermal dispersion from the conductor to the outer shell of the cable was recorded every (1) hour by using the thermometer.

6. Results

a. Results obtained when the cable directly buried in the sand (model 1).

| Time (h) | Conductor (°C) | XLPE Insulation (°C) | PVC outer sheath (°C) |
|----------|----------------|----------------------|-----------------------|
| 0        | 36.2           | 36.1                 | 36.2                  |
| 1        | 57.5           | 48.4                 | 45.2                  |
| 2        | 62.2           | 53                   | 49.6                  |
| 3        | 65.1           | 55.5                 | 52.3                  |
| 4        | 66.6           | 57.2                 | 53.9                  |
| 5        | 67.1           | 57.5                 | 54.1                  |

Figure 8. Variations of temperature obtained from (model 1).

Figure 8 presents the variation of temperatures with the increase in time when the cable direct buried in the sand.

b. Results obtained when the cable inside a PVC pipe surrounded by sand (model 2).
Table 4. The results obtained from (model 2) in each region of the cable

| Time (h) | Conductor (°C) | XLPE Insulation (°C) | PVC outer sheath (°C) |
|----------|----------------|----------------------|-----------------------|
| 0        | 35.8           | 35.5                 | 35.3                  |
| 1        | 67.4           | 56.5                 | 53                    |
| 2        | 74             | 63.3                 | 59.5                  |
| 3        | 76.6           | 65.8                 | 61.7                  |
| 4        | 77.8           | 67                   | 62.4                  |
| 5        | 78.6           | 67.6                 | 62.9                  |

Figure 9. Variations of temperature obtained from (model 2).

Figure (9) presents the variation of temperatures with the increase in time when the cable laid in a PVC pipe.

c. Results obtained when the cable inside an aluminum pipe surrounded by sand (model 3).

Table 5. The results obtained from (model 3) in each region of the cable

| Time (h) | Conductor (°C) | XLPE Insulation (°C) | PVC outer sheath (°C) |
|----------|----------------|----------------------|-----------------------|
| 0        | 36.1           | 35.9                 | 36                    |
| 1        | 63.6           | 55.5                 | 52.9                  |
| 2        | 70.4           | 61.3                 | 58.5                  |
| 3        | 71.9           | 63                   | 60.3                  |
| 4        | 73             | 64.1                 | 61.1                  |
| 5        | 73.7           | 64.4                 | 61.6                  |
Figure 10 presents the variation of temperatures with the increase in time when the cable laid in an aluminum pipe.

7. Discussion and Comparison
Tables (3, 4 and 5) compare the temperature difference for results of the three models. Because of the mutual heating effect, it can be seen that:

a. From the results obtained the conductor temperature in the model (1) are lower than models (2 and 3), and the differences amount to about (11.5°C) for cable located in a PVC pipe and about (6.6°C) for cable located in an aluminum pipe.

b. From the results obtained in the model (3) it was found the conductor temperature can be decreased as compared with a model (2), and the difference amounts to about (4.9°C).

As shown in the table below illustrates the comparison in conductor temperature in each model after (5) hours.

Table 6. The final value of conductor temperature after (5) hours

| Model | Time (h) | Burial depth (cm) | Current (A) | Conductor (°C) |
|-------|----------|-------------------|-------------|---------------|
| 1     | 5        | 80                | 200         | 67.1          |
| 2     | 5        | 80                | 200         | 78.6          |
| 3     | 5        | 80                | 200         | 73.7          |

8. Conclusions
This study presents that the heat transfers mechanisms in underground cable installations. Its considers a system of 12/20 kV XLPEinsulated single core cable with a copper conductor, located in three models was designated for the experiment, Cable located in (sand, PVC pipe, and an aluminum pipe). In addition to, this study has confirmed if an aluminum pipe can be given a better cooling as compared with a PVC pipe. Performed model studies produced the following conclusions:

a. The lowest conductor temperature in the study was noticed when the cable directly buried in the sand.

b. The main finding of the study was a lower conductor temperature when the cable inside an aluminum pipe compared to the PVC pipe.
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