Development of Kelvin/Zisman Probe Based Methodology for Detection of Minor Water Leaks in Underground Pipelines

A F Al Fuhaid

Department of Civil and Environmental Engineering, King Faisal University, P.O. Box: 400 Al-Ahsa, 31982, KSA
Correspondence: aalfuhaid@kfu.edu.sa; Tel.: +966-544-100-436

Abstract. Pipelines are the main means of transportation for liquids such as fresh water. Maintaining the pipelines in a healthy condition is essential to avoid leakage that could affect the economy, environment, sustainability, health and safety. Therefore, valuable water must be well managed and saved by detecting the minor leaks before outrageous losses. The objective of this research is to develop a Kelvin/Zisman probe (KZP) based methodology to detect water leaks in underground supply pipelines. A KZP measures the presence of moisture in soil by assessing the electric potential value (E) in volts that is set-up by the probe. It is designed to detect minor leaks especially in polyvinyl chloride (PVC) and metallic pipes such as steel pipes (ANSI Schedule 40). The developed KZP passes above the ground surface (soil) to take the potential value readings. The reading results confirm the KZP is sensitive to the moisture; so, it can detect water content of soil with 6.7%, 5.6%, and 5.2%, but cannot detect 4.6% or less. Accordingly, the reading results of water contents comply with their R-squared, which are 0.97, 0.96, 0.98, and 0.81, respectively. Furthermore, 6.7%, 5.6%, and 5.2% water content average potential values are 5.6V, 6.2V, and 7.2V, respectively, which are inversely proportional. The proportionality between water content of soil and potential value reading proves the KZP has potential to detect the water leaks.

Keywords: Kelvin/Zisman probe; pipelines; leak; moisture detection

1. Introduction

Pipelines are the main transportation facility for liquids, such as fresh water, sewage systems and drainages [1]. Keeping the pipelines in a healthy condition is essential for avoiding leakage that may lead to catastrophic failure, which would affect the economy, environment, sustainability, health, and safety [2]. The causes of leaks are usually “a crack, break, split, cavitation of the pipe opening, or separation at a joint,” which are called structural failures [3]. Therefore, pipeline inspection mechanism for initial leakage must be applied to fix or replace the deteriorated pipe [3]. If the pipelines are properly designed, inspected, and maintained, they can last for decades without problems [5]. One of the significant contributions of the proposed probe is that, it is capable of detecting very little amount of moisture. Consequently, it can enable maintenance teams to detect leaks at an early stage before the situation deteriorates. The detection of moisture can be achieved during normal rounds of inspection. The objective of the paper is to develop a Kelvin/Zisman probe (KZP) based methodology, which is cheap and easy to follow, to detect water leaks in underground supply pipelines (buried infrastructure). A KZP can measure the presence or rate of moisture in the soil by assessing the electric potential value (E) in volts that is set-up by the probe.
2. Motivation
A problem commonly encountered in Saudi Arabia by civil, utilities and environmental engineers, is to detect leaks of fresh water in underground PVC and ductile iron pipelines. The existence of the leak is usually reported by residents, when they start experiencing low water pressure at their homes, or when the water leaks start accumulating on the ground of their complex. However, due to lack of know-how, it is not easy for the ordinary citizen to pin-point the location of leak; it takes a lot of digging and searching to locate the deteriorated pipe, at high expenses in terms of time and costs to the individual. Since, the water resources in Saudi Arabia are very scarce due to the dry climate (semi-desert climate), the valuable water needs to be managed well. Therefore, it is extremely important to conserve water and to detect leaks very quickly.

The KZP can be adapted to detect water pipeline leaks in Saudi Arabia for several reasons. First, Saudi Arabia’s soil is uniform because only fine aggregate (sand) is used to cover pipelines even if the original soil, that is excavated, is clay or rock. Also, the soil is dry just like any other medium such as concrete. Second, the groundwater level is very low (below any piping system), so it will not disturb readings of KZP. Third, the depth between the top of pipe and ground surface is low (between 0.6 and 2 m), which enables easy implementation of the probe.

3. Literature Review of Existing Methods of Detecting Leaks
A variety of methods for leakage detection in pipelines have been developed or proposed. A review of these methods and their advantages and disadvantages are summarized in Table 1. In practice, the common tools used to detect water leaks for underground pipelines are (1) acoustic equipment, and (2) leak noise correlator (LNC). The acoustic equipment contains an electronically amplified stick or manually placed geophones and ground microphones that are placed above the ground surface with the pipe underneath and the equipment is moved along to detect the leaks. The leak noise correlator identifies and electronically analyzes noise coming from two microphones that are connected to the pipe in two separate points to locate the leaks by knowing the speed of the wave in the pipe [1, 2, 4, 5, 6, 7]. The acoustic method equipment and the leak noise correlator cannot easily detect water leaks or locate small leaks especially from plastic such as polyvinylchloride (PVC) and steel underground pipelines [1, 2, 4]. For example, acoustic methods can locate the leak position 70 cm away from a leaking source while the correlator system can do it within 50 cm from the source [4]. In addition, both methods are expensive and need a specialist to operate them [1, 2]. Also, they may be disturbed by environmental conditions such as noise, which affects the ability to locate the exact leakage point [4]. Furthermore, the maximum pipeline length or inspection range, the tool can be set-up for measuring, differs depending on the material of the pipeline. For example, the LNC’s inspection range pipe is from 15 to 1000 m for metallic pipes, but 15 to 100 m for plastic pipes, which is very slow for plastic types and requires access to the pipe [2]. The LNC cannot perform efficiently in unclean and large diameter pipes. A new method, continuous wave Doppler sensing technique cannot work efficiently where pipelines are buried deep in the ground or in very damp soils [4]. Therefore, the aim of the proposed method is to develop a Kelvin/Zisman probe that has the ability to overcome some of these obstacles and can be used in Saudi Arabia.

Table 1. Advantages and Disadvantages of Available Methods for Leakage Detection [1, 2, 4, 7].

| Methods                          | Advantages                                                                 | Disadvantages                                                                 |
|----------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|
| **A. Visual techniques**         |                                                                           |                                                                              |
| 1. Visual inspection             | Accurates for big and accessible pipe/sewer/tunnel.                      | Slow; requires professional and human access.                                |
| 2. Closed-circuit television     | Real time assessment; used for sewer pipelines to detect voids before     | Slow; inaccurate; poor quality images and only for above the water surface   |
|       (CCTV)                     | failure occurs.                                                          | so limited information; lack of geometric references; a sewer length to     |
|                                  |                                                                           |                                                                              |
### 3. Sewer scanner evaluation technology (SSET)

Using post processing methods increases survey speed; expert required. 

Depends on images only.

### B. Electromagnetic (EM) and radio frequency (RF) methods

**1. Magnetic flux leakage (MFL)**
- Good for steel pipes; detects corrosion pits and small defects.
- Requires access to pipe and cleaning of pipe interior; requires close contact with the pipe, which is hard to maintain and may damage the lining of the pipe; struggles to detect short and shallow defects.

**2. Eddy current technique**
- Good for small metallic pipes down to 100 mm; can be run in wet or dry pipes.
- Requires Access to pipe; inspection depth depends on wall depth of the pipe.

**3. Hydroscope technology (RFEC)**
- Good for big metallic pipes; detects corrosion pits and even through holes.
- Requires access to pipe; only ≤ 30 cm² pits size can be detected.

**4. Rapid magnetic permeability scan (RMPS)**
- Good for big metallic pipes for ≥ 100 mm diameter; quick and easy to operate; real time assessment.
- Not suitable for thick pipe coating or lining.

**5. Low frequency electromagnetic field (LFEM)**
- Good to measure the earth resistivity; quick and easy to operate; A non-invasive system.
- Requires high conductive ground surface.

### C. Acoustic and vibration techniques

**1. Sonar**
- Measures pipe wall deflection, the corrosion loss, and volume of debris.
- Can be operated in air or water, but not both simultaneously

**2. Vibro-acoustics**
- Good for all types of pipes and cables; detects leaks in water pipelines.
- Geophones need to be half-buried, so not work for hard ground surfaces; bends in the pipework can pose problems for signal propagation; depends on soil conditions.
| 3. Impact echo/spectral analysis of surface waves | Overall condition of pipe can be assessed; works for prestressed concrete pipes. | Requires access to pipe; geophones need to be mounted onto pipeline. |
| 4. Leak noise correlator (LNC) | is the most common technique for leak location; works in distribution network; inspection range 15-2000 m (for plastic pipe 15-100 m); can detect leak size 0.031 l/s within 0.6 m from the leak point. | Good in clean, small diameter metallic pipes; slow for plastic. |
| 5. Listening stick | Simple and cheap. | Needs to know location and direction of pipeline as access to valves is required; background noise can cause erroneous detection; only suitable for pressure pipes; level of sensitivity varies depending on pipe material; not for plastic pipes. |
| 6. Ultrasonic guided waves | Good for corrosion detection; fast. | Requires access to pipe. |
| 7. Acoustic Pulse Reflectometry (APR) | Detects blockages within a pipe and leaks. | Requires access to pipe. |
| **D. RFID (sensor technique)** | Locates the position of underground utilities; can detect in wet conditions; detect water leaks. | Needs to be attached to utilities; is dependable on the lifetime of the battery. |
| **E. Other techniques** | | |
| 1. Infrared thermography | Trenchless method, used to locate underground objects like pipelines, boulders, and voids. | Ground cover and wind speed can influence results; cannot measure depth. |
| 2. Continuous wave Doppler sensing | Detects and locates the exact leakage point; good for many environmental conditions, soil conditions, pipeline material; good for plastic (PVC & HDPE). | Takes > 3 minutes to detect water leakage; cannot work efficiently where pipelines are buried deep in the ground and in very damp soils. |
| 3. Laser surveys | Can determine internal profile of the pipe along its length. | Is used above water surface in sewer and water pipes. |
| 4. Tracer gas technique (TGT)/gas injection | Multiple leak locations can be found in a single pipe section; inspection range up to 1m of pipe length; locates leaks within 1m from the leak point. | Expensive. |
| **F. Combined sensors** | | |
| 1. Broadband electromagnetics/Wave impedance probe (WIP) | Real time assessment; good for all pipes except ferrous pipes; can be used to assess conduit surrounds and pipe condition depending on the sensor and output strength selected; available in both ‘surface’ and ‘in-pipe’ systems; capable of surveying | Received signals usually requires post processing but major anomalies can be identified on-site. |
up to 300 m of active sewer or storm water networks.

| Pipe inspection real-time assessment technique (PIRAT) | Detects the type, location and size damage in a sewerage system; can see whole pipe interior; increased survey speed since it uses post processing method. | Sonar scanner has low survey speed and low resolution; sonar surveys only detect gross defects; laser scanner does not work well for certain types of pipe wall (e.g., brick sewers). |
|------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Acoustic Fiber Optics (AFO)                          | Suitable for long term monitoring; one sensor and data acquisition system can be used to monitor up to 12.4 miles of pipe | Expensive; fibers are easy to break and difficult to repair. |
| Sahara system                                        | Real-time system; locates leaks as small as 0.0026 l/s within 50 cm from the leak point. | Requires access to pipe; hydrophone on umbilical cable inside pipe needs to be traced on surface of the ground in order to pinpoint leaks. |
| Integrated pipes                                     | Good for plastic pipes.                                                         | Expensive compared to normal pipes; when broken, it is hard to Repair. |
| Water audits                                         | Cheap; can detect area of leaks.                                                 | Cannot detect the number of leaks and the precise position of the leaks; require isolation of zones. |
| Pig-mounted acoustic sensing (PMA)                   | Inspection range up to 2000 m of pipe length; detects leak size between 0.0003 to 0.003 l/s within 0.5 m of leak source. | Expensive; requires a trained person; requires access to pipe and clean pipes, so it is difficult to apply this methodology to old pipes where there may be heavy corrosion. |

4. Principle of Kelvin/Zisman Probe on Soil

The developed Kelvin/Zisman probe (KZP) is designed to detect minor leaks especially in polyvinyl chloride (PVC) and metallic pipes such as steel pipes (ANSI Schedule 40). However, KZP does not work very well in damp soils. The disk of the probe is passed above the ground surface (soil or concrete pavement) to take the electric potential value readings using a high impedance voltmeter. In this research, the KZP is assembled using the electronic circuits shown in Figures 1 and 2. It is used as an indirect method to measure soil conductivity to determine the leaks of pipes. KZP measures the electric potential value (E) between a working surface (W = ground surface) and a reference surface (R = vibrating disk). R or disk is vibrated by the loud speaker that produces audio frequency signals at 200 Hz, which is supplied from a sine-wave generator (Figure 1 and 2) (Appendix A). W and R look like a capacitor that since there is no contact between them (Figure 3). For PVC pipe measurements, the disk (R) made of stainless steel is connected to a Zinc (Zn) or a galvanized steel bar that is inserted in the ground close to PVC pipe (Figure 1) through electronic conductor. However, a metallic pipe is connected directly to the disk (Figure 2) through electronic conductor. The galvanized steel bar surface or metallic pipe surface is connected to the ground surface mainly by water or minerals in the soil, which acts like electrolyte. And the gap or space (h) between the surface of soil and the disk acts like a capacitor, where E values can be obtained. E values are peak to peak voltage readings that can be taken from oscilloscope.

The equation between electrical charge (Q) and (E) across the capacitor with capacitance (C) is [8]:

\[
E = \frac{Q}{C} \tag{1}
\]

\[
C = \frac{\varepsilon A}{h} \tag{2}
\]
\[ \varepsilon = \frac{\varepsilon_r}{\varepsilon_0} \]  

(3)

where,
\( \varepsilon \) is permittivity of the dielectric;
\( \varepsilon_r \) is the relative permittivity;
\( \varepsilon_0 \) is constant, permittivity of air or vacuum = 8.85x10\(^{-12}\) (F/m); and
\( A \) is the smaller cross-sectional area of the capacitance, which is the disk area.

The difference between the absolute potential \( \Psi_R \) (the reference surface, disk) and the absolute potential \( \Psi_W \) (the working surface, soil surface) is called the potential difference (E) in volts measured by KZP:
\[
E = \Psi_R - \Psi_W
\]

(4)

The mechanism for measuring the value of E using KZP is to use two different metals: one is stainless steel disk for \( R \), and the other is galvanized steel bar or metallic pipe (M) for \( W \). The potential difference (E) occurs when two different conductors or semiconductors with different work function contact together. The work function (\( \Phi \)) is the energy needed to move an electron from a bulk surface to point that is away from its surface [9]. For example in the electronic circuit of KZP, negative charges in the material surface with high work function such as stainless steel disk repel all negative charges in the other material surface with small work function such as Zink bar and pile up positive charges.

E value is calibrated by KZP through a schematic system as illustrated in Figure 3:
\[
X_{MR} = \Phi_R - \Phi_M \quad \text{(corresponding interfacial potential difference)}
\]
\[
X_{AR} = \Phi_R - \Psi_R \quad \text{(medium air interfacial potential difference)}
\]
\[
X_{AW} = \Phi_W - \Psi_W \quad \text{(medium air interfacial potential difference)}
\]
\[
X'_{WM} = \Phi_W - \Phi'_W \quad \text{(metal electrolyte interfacial potential)}
\]
\[
\Delta \Phi_W = \Phi'_W - \Phi_W \quad \text{(resulting difference)}
\]

Equation (4) therefore become:
\[
E = X'_{WM} + X_{MR} - X_{AR} + X_{AW} + \Delta \Phi_W
\]

(5)

Figure 1. Design of KZP with Zinc or Galvanized Steel Bar for PVC Pipe.
5. Methodology
To achieve the research objective, a laboratory study was designed and carried out to evaluate the feasibility of the proposed KZP for water leak detection of buried pipes. In the laboratory study, the KZP was first designed and fabricated for the purpose of the leak detection. The potential value (E) was determined through a capacitor gap (h = 1 cm & 2 cm) by KZP between working surface (soil) and reference surface (disk) (Figure 3). The disk was connected to galvanized steel bar or to steel pipe through an electronic conductor. And a stable E was measured by scanning the disk over the centerline of the flat soil surface at every 5 centimetres of total horizontal distance 40 centimetres except the end edges (Figure 4, Tub Top Plan), which means 7 potential values for one test.

There were four soil moisture levels to be tested as shown in Figure 5. The effectiveness of the fabricated KZP was evaluated indoor at temperature 22°C with an experimental design and factors with their levels as follows to measure the potential (E). The experimental design is summarized in Figure 5:

1. A plastic chamber (dimensions: 40 cm diameter, 80 cm height) filled with wet soil (sand) was used to simulate field test condition to detect the leaks. A sample of the same sand was taken to the lab test to measure its moisture level. Then, the soil was exposed to the sun for a day to be dried partially for testing with less moisture level. This action had been done three times; so, there were four soil moisture levels.

2. Two types of materials were used to run the experiment: galvanized steel bar, and steel (ANSI Schedule 40) (1” diameter). The full details of design chamber are illustrated in Figure 4.

3. Two depths (d) of pipe below ground surface were examined: 30 and 60 centimetres (Figure 5) to verify if the KZP is affected by the depth of pipe, or not.
6. Results and Discussions

Table 2 shows the summary of 10 test conditions. The average E of 2 replicates was taken under each test condition (2 h heights of capacitors; 3 levels: 2 d depths of pipe plus a bar inserted), and there were 7 potential values during each test for all 4 water contents (Figure 4 & 5). Therefore, the total number of average potential values is $4 \times 2 \times 3 \times 7 = 168$. The experimental results reveal that as water content in the soil decreases, the potential value (E) increases; as shown in Figure 6, 6.7%, 5.6%, 5.2%, and 4.6% water contents have an average E readings 5.6V, 6.2V, 7.2V, and 8.3V, respectively. That means the dielectric space that is located between the disk and ground surface has amount of moisture, because of water content of sand that changes the permittivity of the dielectric (ε). Therefore, as water content of sand increases, the relative permittivity value (εr) increases, which in turn increases the value of the capacitance (C) in equation (2). So, the value of potential (E) decreases as C value increases to comply with equation (1).

Also, factor factorial design analysis was used to investigate each average E of the experiment with all combinations of the levels of factors [10]. There are two factors (height of capacitor: $h = 1$cm and 2cm) at three levels (depth of pipe: $d = 30$cm, 60cm, and bar inserted 60cm depth). 42 potential readings were run for four water contents and tested at each combination of height of capacitor and depth of pipe or bar (Table 2). Based on factor factorial design analysis of the experimental results and after fine-tuning the measurement parameters, the developed KZP can perfectly detect 6.7%, 5.6%, 5.2% water contents as approved by Table 3 because their P-values are less than 0.05; therefore, their models are significant except 4.6% water contents. Significant parameter such as model (water content), factor, or level means its presence indeed affected the readings of the prob. In the Table 3, letter A in the table represents the height ($h = 1$ and 2 cm) of the capacitor and letter B represents the depth of pipe ($d = 30$ and 60 cm) or bar inserted; so, letters A and B are significant for 6.7% and 5.6% water contents but not for 5.2% water content. However, the combination of AB letters are not significant for 6.7%, and 5.6% water contents. Also, plots of residuals versus height of disk (Figure 7) and versus depth of steel pipe and steel bar (Figure 8) prove that h and d are significant parameters for 6.7% and 5.6% water contents.
because their residuals are constant variance; they are not randomly scattered such as 5.2% water content, or concentrated around zero such as 4.6% water content. According to Figure 9, R-squared of 6.7%, 5.6%, and 5.2% water contents are 0.97, 0.96, and 0.98, respectively; these indicate that their normal plots of residuals are linear or normally distributed that enhance KZP can detect them. On the other hand, 4.6% water content normal plot of residual is not normally distributed because its R-squared is 0.81.

**Table 2.** Potential (Volts) Data for 6.7%, 5.6%, 5.2%, and 4.6% Water Contents.

| Water Content | Source | DF | SS  | MS  | F   | F critical | Significant |
|---------------|--------|----|-----|-----|-----|------------|-------------|
| 6.70%         | Model  | 5  | 0.512364 | 0.102473 | 21.86594 | 2.477169 | 5.25E-10 | Yes |
|               | A      | 1  | 0.242288 | 0.242288 | 51.70016 | 4.113165 | 1.85E-08 | Yes |
|               | B      | 2  | 0.265815 | 0.132907 | 28.36016 | 3.259446 | 4.02E-08 | Yes |
|               | AB     | 2  | 0.004261 | 0.002131 | 0.0454614 | 3.259446 | 0.638287 | No |
|               | Error  | 36 | 0.168711 | 0.004686 | 0.168711 | 0.004686 | 0.168711 | 0.004686 |
|               | Total  | 41 | 0.681074 | 0.016271 | 0.681074 | 0.016271 | 0.681074 | 0.016271 |

**Table 3.** Analysis of Variance for 6.7%, 5.6%, 5.2%, and 4.6% Water Contents.
|    | SSsubtotal | 0.512364 | 0.063697 | 7.158259 | 2.477169 | 9.72E-05 | Yes | 5.60% |
|----|------------|----------|----------|----------|----------|-----------|-----|-------|
| Model | 5 | 0.318486 | 23.12772 | 6.177667 | 3.259446 | 0.004937 | Yes | A |
| A | 1 | 0.205800 | 0.054971 | 0.154121 | 0.259446 | 0.857731 | No | |
| B | 2 | 0.109943 | 0.01371  | 0.259446 | 0.857731 |          |     |      |
| AB | 2 | 0.002743 | 0.008898 | 0.857731 |          |          |     |      |
| Error | 36 | 0.320343 |          |          |          |          |     |      |
| Total | 41 | 0.638829 |          |          |          |          |     |      |
| SSsubtotal | | 0.318486 |          |          |          |          |     |      |

|    | SSsubtotal | 10.44653 | 2.089306 | 49.54294 | 2.477169 | 3.81E-15 | Yes | 5.20% |
|----|------------|-----------|----------|----------|----------|-----------|-----|-------|
| Model | 5 | 10.44653 | 0.170372 | 4.039968 | 4.113165 | 0.051974 | No | A |
| A | 1 | 0.170372 |          |          |          |          |     |      |
| B | 2 | 4.250358 | 2.125179 | 50.39358 | 3.259446 | 3.67E-11 | Yes | |
| AB | 2 | 6.025801 | 3.012901 | 71.44378 | 3.259446 | 2.93E-13 | Yes |      |
| Error | 36 | 1.518179 | 0.042172 |          |          |          |     |      |
| Total | 41 | 11.96471 | 10.44653 |          |          |          |     |      |
| SSsubtotal | | 10.44653 |          |          |          |          |     |      |

|    | SSsubtotal | 0.014048 | 0.002810 | 2.400000 | 2.477169 | 0.56114  | No | 4.60% |
|----|------------|----------|----------|----------|----------|-----------|-----|-------|
| Model | 5 | 0.014048 | 0.002143 | 1.830508 | 4.113165 | 0.184504 | No | A |
| A | 1 | 0.002143 |          |          |          |          |     |      |
| B | 2 | 0.011548 | 0.005774 | 4.932203 | 3.259446 | 0.012790 | Yes | |
| AB | 2 | 0.000357 | 0.000179 | 0.152542 | 3.259446 | 0.859074 | No |      |
| Error | 36 | 0.042143 | 0.001171 |          |          |          |     |      |
| Total | 41 | 0.056190 | 0.014048 |          |          |          |     |      |
| SSsubtotal | | 0.014048 |          |          |          |          |     |      |
Figure 7. Plot of Residuals versus Height of Disk (h) for 6.7%, 5.6%, 5.2%, and 4.6% Water Contents.

Figure 8. Plot of Residuals versus Depth of Steel Pipe and Steel Bar for 6.7%, 5.6, 5.2%, and 4.6% Water Contents. The d = 0 readings refer to bar inserted 60 cm depth.
Figure 9. Normal Probability Plot of Residuals for 6.7%, 5.6%, 5.2% and 4.6% Water Contents.

7. Conclusion

- A Developed Kelvin/Zisman Probe is used to measure potential differences for four water content of sand: 6.7%, 5.6%, 5.2%, and 4.6%; and its average readings are 5.6V, 6.2V, 7.2V, and 8.3V, respectively.
- The KZP can perfectly detect pipe leakage of water, if the sand reaches water content 6.7%, 5.6%, and 5.2% as approved by using factor factorial design analysis with R-squared 0.97, 0.96, and 0.98, respectively.
- Nevertheless, KZP is not sensitive to sand with 4.6% water content or dryer because its R-squared is equal to 0.81.
• The readings of each water content for two factors of capacitor heights (h = 1cm, and 2cm) and three levels of depths (d = 30cm, and 60cm of pipe depths and bar inserted 60cm depth) are approximately the same result.
• However, the readings of 5.2% with height of capacitor 1 cm and 2cm are not convergent.
• According to the factor factorial design analysis results, the readings of KZP are acceptable at two factors and three levels.
• In general, as water content in sand increases, the KZP readings decrease. Therefore, the presence of water in the sand is significant parameter in the KZP readings.

8. Appendix A

Figure A1. Actual Design of KZP.

Figure A2. The Bottom of Loud Speaker.

9. References
[1] Hao, T., Rogers, C., Metje, N., Chapman, D., Muggleton, J., Foo, K., Wang, P., Pennock, S., Atkins, P., Swingler, S., Parker, J., Costello, S., Burrow, M., Anspach, J., Armitage, R., Cohn, A., Goddard, K., Lewin, P., Orlando, G., Redfern, M., Royal, A., Saul, A. (2011, November 29). Condition assessment of the buried utility service infrastructure, Tunnelling and Underground Space Technology 28 (2012) 331–344.
[2] Puust, R., Kapelan, Z., Savic, D., Koppel, T. (2010, Feb 24). A review of methods for leakage management in pipenetworks, Urban Water Journal, 7:1, 25-45, DOI: 10.1080/15730621003610878.
[3] Najafi, M. (2014, January 29). Pipeline rehabilitation systems for service life extension, Woodhead Publishing Limited, 2011, Pages 262-289.
[4] Bimpas, M., Amditis, A., Uzunoglu, N. (2010, January 12). Detection of water leaks in supply pipes using continuous wave sensor operating at 2.45 GHz, Journal of Applied Geophysics 70 (2010) 226–236.
[5] Kishawy, H., Gabbar, H. (2010, April 30). Review of pipeline integrity management practices, International Journal of Pressure Vessels and Piping 87 (2010) 373e380.
[6] Rizzo, P. (2010, February 23). Water and Wastewater Pipe Nondestructive Evaluation and Health Monitoring: A Review, Hindawi Publishing Corporation, Advances in Civil Engineering, Volume 2010, Article ID 818597.
[7] Liu, Z., Kleiner, Y. (2012, June 16). State of the art review of inspection technologies for condition assessment of water pipes, Measurement 46 (2013) 1–15. 2015.
[8] Sagüés, S., Walsh, M. (2011, December 1). Kelvin Probe electrode for contactless potential measurement on concrete – Properties and corrosion profiling application, Corrosion Science 56 (2012) 26–35.

[9] Klein, U., Vollmann, W., Abatti, P. (2003, August). Contact Potential Differences Measurement: Short History and Experimental Setup for Classroom Demonstration, IEEE TRANSACTIONS ON EDUCATION, VOL. 46, NO. 3.

[10] Montgomery, D. (2013). Design and Analysis of Experiments-8th Edition. United States, Hoboken, New Jersey: John Wiley & Sons, Inc. ISBN 978-1-118-14692-7.

Acknowledgments
The author acknowledges the Deanship of Scientific Research at King Faisal University for the financial support under Nasher Track (Grant No. 206047).