

In-house development of neutron moisture gauge for field measurement

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Abstract. The measurement of moisture content in soil is based on the principle of neutron back scattering. In this principle, when fast neutrons emitted from a radioactive source collide with hydrogen atoms their energies are much greater reduced than colliding with other elements. The number of slowed down neutrons, hence, represents the number of hydrogen atoms present in the vicinity of the source. As water is the main contributor of hydrogen atoms in a soil medium, the moisture content in soil, therefore, can be measured based on this principle. An in-house developed probe containing a source of fast neutrons and a slow neutron detector was inserted into soil at different depths under the ground level. The probe was made of high density polyethylene and connected to a suitably calibrated detection system by a single cable. The moisture content was determined from the slow neutron count rate. The results of field measurement tests were reported and discussed.

1. Introduction

Water content has an important role in various field applications, such as hydrology, dam construction, railway construction process and agriculture, etc. The conventional technique used in water content measurement is gravimetric sampling. However, this direct method requires great amount of time, effort and money. On the other hand, neutron moisture gauge is considered a potential candidate for water content measurement as it fulfills all general requirements for soil moisture measurement with less expenditure as follows: (1) frequent measurement (2) estimation of moisture content within the upper 1 – 2 m of the soil and (3) moisture measurement over large areas [1].

Neutron moisture gauge technique is based on the principle of neutron backscattering. This principle relies on the fact that collision of high-energy neutrons with hydrogen atoms can reduce much greater amount of their energies than colliding with atoms of other elements. Therefore, the number of hydrogen atoms present in the soil sample can be measured from the number of neutrons slowed down [2]. As water is the main source of hydrogen in soil, the number of hydrogen atoms detected by this method can directly represent the moisture content in the sample.

The present study has contributed to a better understanding of the measurements of water content profile in soil by neutron probe at different depths (10 – 100 cm) under the ground level.

2. Equipment design and setup

2.1 Neutron probe design

The neutron probe was made of cylindrical polyethylene. The probe was designed to be spacious so that it could contain a neutron source and the corresponding detector. A 300 mCi $^{241}\text{Am-Be}$ neutron source and a BF_3 proportional counter were used as the source and detector respectively. In addition, the neutron probe was designed to emit as high fast neutron fluence as possible and be durable in field measurement. A schematic diagram and an image of the neutron probe are shown in Figure 1.

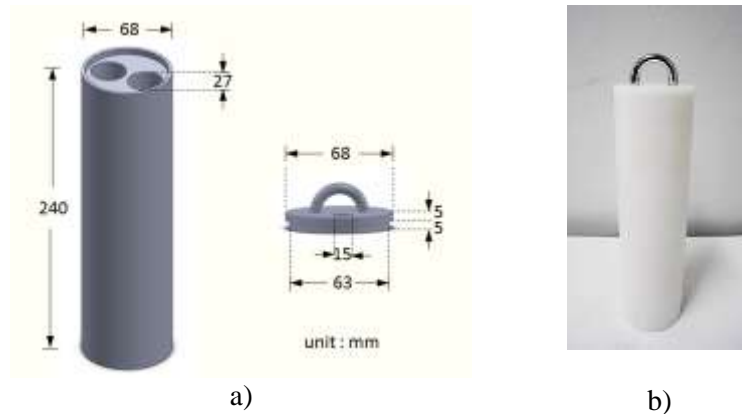


Figure 1. a) A schematic diagram of polyethylene containing the source and detector
b) The neutron probe

2.2 Experimental setup

The experimental setup was based on the nuclear instrument modules. The detector was operated at 30% of plateau length. The block diagram of the setup is shown in Figure 2.

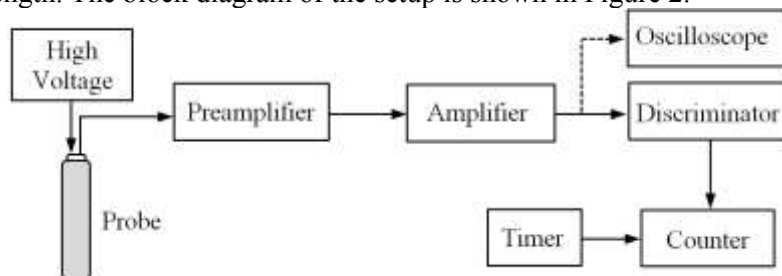


Figure 2. A block diagram of the neutron detection setup in field measurement

3. Field Measurement

In this study, gravimetric measurement (direct method) was used for comparison with the neutron probe measurement. Soil samples at every 5 cm depth under the ground level were collected by sequential insertions of an aluminium access tube with 2.5-inche diameter. After soil sample collection, the direct method was applied to determine the water content by drying the soil samples at 105 °C for 24 hrs to gain a constant weight. The results were expressed as percent of water content.

For neutron backscattering method, the probe was connected to a preamplifier and the measuring system. The schematic diagram of the probe measuring underground and the experimental setup are shown in the Figure 3. The probe was inserted into the borehole and the measurement was done at every 5 cm depth for 30 s until reaching 100 cm depth.

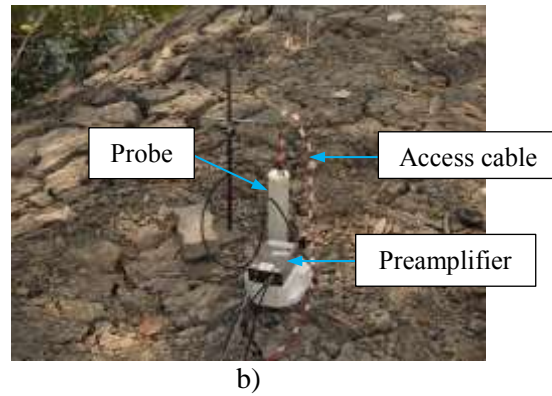
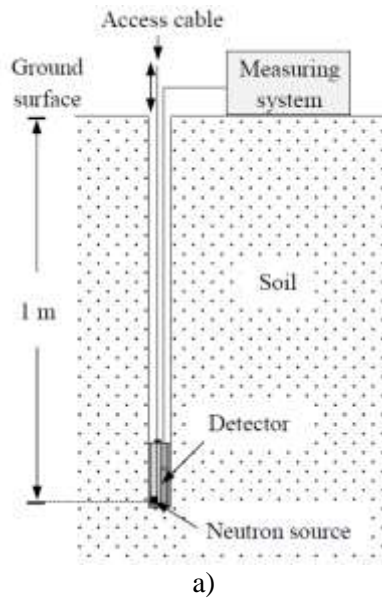


Figure 3. a) Schematic diagram of neutron moisture gauge measuring under ground level b) Picture from field measurement

4. Results and discussion

In the principle of neutron interaction, elastic scattering is the dominant mode for energy loss of fast neutron to epithermal neutron. In this interaction the kinetic energy of the neutron is partially transferred to the target nucleus. The maximum energy loss of neutron based on conservation of energy and momentum from a head-on collision is calculated by the following equation [3]:

$$E_1 - E_2 = \frac{4A}{(A+1)^2} E_1$$

where E_1 and E_2 are the energies of the neutron before and after collision, respectively, and A is the mass number of the nucleus.

After the soil samples were taken for water content calculation using the gravimetric method, elemental concentrations in the soil samples were analysed using a portable X-ray fluorescent (XRF), manufactured by Olympus model DELTA. The results of average major and minor elemental concentrations are summarized in Table 1.

Table 1. Elemental concentrations in the soil samples, except for the samples from the depth at 55 – 75 cm, analysed using portable XRF.

Elements	Range of concentrations	Elements	Range of concentrations
Light elements	57.20 – 60.13%	Zn	73 – 147 µg/g
Si	22.97 – 28.06%	Sr	62 – 106 µg/g
Al	6.63 – 7.99%	Y	31 – 48 µg/g
Fe	3.37 – 7.68%	Ni	27 – 43 µg/g
K	1.16 – 1.51%	Pb	23 – 46 µg/g
Ti	3619 – 4610 µg/g	Th	15 – 30 µg/g
Ca	684 µg/g – 1.34%	Nb	21 – 30 µg/g
Mn	375 – 941 µg/g	Cu	20 – 34 µg/g
Zr	168 – 232 µg/g	As	4 – 22 µg/g
Rb	130 – 158 µg/g		

The results of water content from gravimetric method and the measurements of neutron count rate at every 5 cm depth from 10 – 100 cm under the ground level are shown in Figure 4.

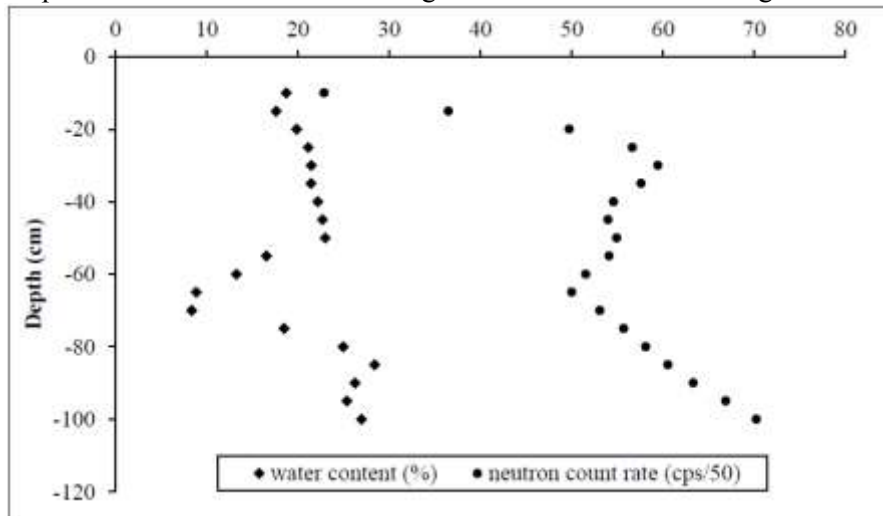


Figure 4. Soil water content distribution from gravimetric method in comparison with neutron count rate at depth of 10 – 100 cm under the ground level.

Figure 4 presents the profile of the soil water content from the gravimetric method compared with the neutron count rate obtained from the depth 10 – 100 cm under the ground level. The results indicated that at the depth from 10 cm to 25 cm under the soil surface, the slow neutrons might be due to the erratic loss of neutron to the atmosphere. It is difficult to separate the effects from water content and bulk density. On the other hand, at the depth lower than 25 cm, one can be sure that the slow neutron cloud is completely inside the soil. The data shown in Figure 5 also presents the neutron count rate as a function of soil water content distribution obtained from the depth 30 – 100 cm.

The calibration equation was established for the low range of water content found in the soil samples. The calibration equation between water content and neutron count rate was satisfactory for the measurement of the water content providing a linear range of values.

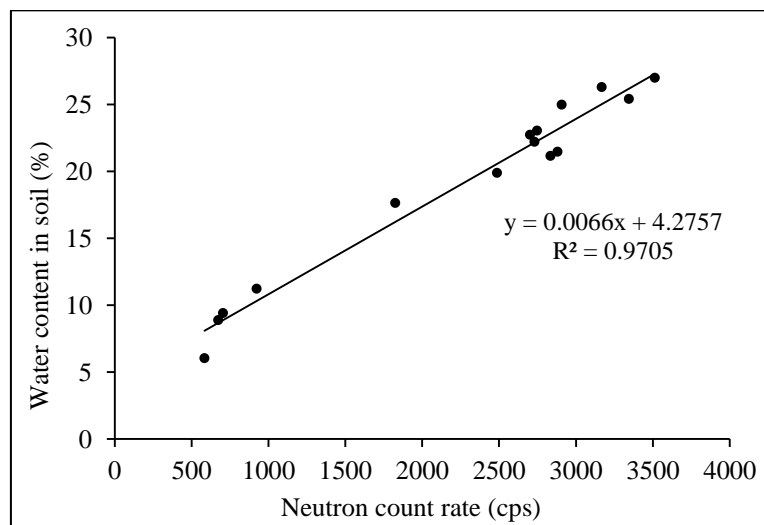


Figure 5. Neutron count rate as a function of soil water content distribution in the soil samples

In addition, according to the results in Figure 4, it is evident that the characteristics of moisture content in soil can be separated into 3 ranges. 1) At 10 to 25 cm under the ground surface, the moisture content level is directly proportional to the depth. 2) At 30 to 80 cm under the ground surface, the moisture content level is nearly constant. 3) At the depth greater than 80 cm, the moisture content level increases with the depth following the trend at 10 to 25 cm. Moreover, the results in Figure 4 also suggest that neutron scattering technique can be used to distinguish soil horizons. As it is obviously seen at the depth from 55 to 70 cm, the moisture contents decrease abruptly. This is due to the fact that the soil in that range consists of crushed stone left from road construction in the past. The average major and minor elemental concentrations in the soil samples collected from 55 – 70 cm shown in Table 2 correspond to the elemental concentrations detected in crushed stone.

Table 2. Average major and minor elemental concentrations in the soil samples collected from 55 – 70 cm analysed using portable XRF

Elements	Range of concentrations	Elements	Range of concentrations
Light elements	56.66 – 58.81%	Zn	113 – 170 µg/g
Si	15.15 – 22.97%	Sr	106 – 295 µg/g
Al	5.03 – 7.22%	Y	23 – 32 µg/g
Fe	3.47 – 5.22%	Ni	23 – 32 µg/g
K	0.77 – 1.31%	Pb	19 – 35 µg/g
Ti	3210 – 4190 µg/g	Th	14 – 16 µg/g
Ca	4.21 – 16.61%	Nb	11 – 26 µg/g
Mn	645 – 1458 µg/g	Cu	32 – 72 µg/g
Zr	100 – 168 µg/g	As	19 – 32 µg/g
Rb	66 – 138 µg/g		

5. Conclusions

A neutron moisture gauge for field measurement of soil moisture content was developed. The probe was made of high density polyethylene and consisted of an ^{241}Am -Be neutron source and a BF_3 proportional detector. The preliminary results of the neutron probe response were collected at different depths (10 cm – 100 cm) under the ground level. The measurement using the gravimetric method was also done for comparison. The results from neutron probe measurement was satisfied providing a linear calibration curve ($R^2 = 0.9705$) with the water content taken from the direct method. It was proven that the probe developed can be used to determine water content in general.

Acknowledgments

The authors would like to thank Mr.Manoach Chimtin and Mr.Panya Hemla, staff of the Nuclear Reactor Center, Thailand Institute of Nuclear Technology for their support in this project.

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