# THE INFLUENCE OF PACKING DENSITY ON HYDRAULIC PROPERTIES OF NEEDLEPUNCHED NONWOVEN GEOTEXTILES

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## ABSTRACT

*The application of nonwoven geotextile isdetermined by its performance, which is governed by its properties.Packing density is an important parameter affecting the performance of nonwoven geotextiles.This work presents a study on the influence of structural parameters such aspacking density or fabric porosity on hydraulic properties (permittivity and transmissivity) of needle-punched nonwoven geotextiles.Samples of PET and PP needle-punched nonwoven geotextile of 500 g/ $m^2$mass per unit area, and three differentneedle penetration depthsof 8, 10 and 12 mm have been used to obtain three differentthicknesses of geotextiles.Results of permittivity and transmissivity were compared with results of packing density and porosityto check if there is a correlation between them or not. The experiment showed that permittivity and transmissivitywere influenced by fabric packing density or porosity. Results of packing density can be used as arough indicator for both permittivity and transmissivity properties by only knowing the fabric thickness, mass per unit area and fiber density.*

***Keywords: Needle-Punched, Nonwoven, Geotextile, Permittivity, Transmissivity, Packing Density, Porosity.***

## I. INTRODUCTION

### 1.1 Geotextiles

Geotextiles are permeable fabrics used in various fields of civil engineering andearthwork projects. Geotextile materials are increasingly used in many different geotechnical and geoenvironmental engineering applications to perform various functions such as filtration, drainage. reinforcement separation, soil protection[1], [2]

The fabrics are usually comprised of synthetic polymer fibers that are in woven, nonwoven, or knitted form[3].Geotextiles used in the construction sector are mainly produced by non-woven technology, representing approximately 70% of the whole amount of fabrics used for this purpose[2].

Prior to the development of geotextiles, thick layers of natural materials such as sand, gravel, and rock were used in earthwork projects to perform many of the functions now assumed by geotextiles.

Geotextiles offer a potentially large savings in cost and can reduce the time of construction as compared to the use of natural materials such as sand and gravel for filters and drains.

Although geotextiles are typically designed to function, there are often several functions involved with a given application. Typically, a primary function, such as filtration, also relies on a secondary function, such as drainage, for the application to be successful[3], [4].

## 1.2 Geotextiles Hydraulic Properties

Geotextiles are among the most widely used syntheticmaterials to improve the soil hydraulic properties fromfiltration and drainage aspects. The geotextile hydraulic behavior is of great usage in the design of landfill covers; design of embankments and irrigation structures drainage systems, and in the design of protection systems in river engineering[5].

It is necessary to obtain the geotextile hydraulic properties in order to evaluate the performance of its function. The filtration and drainage functions differ primarily in terms of the direction of liquid flow .The function of geotextile filtration involves the movement of liquid through the fabric itself while at the same time, the fabric retains the soil on its upstream side. The drainage function of a geotextile involves transmission of liquid in the plane of the fabric without soil loss[6].

Since geotextiles have the capability of water transmission parallel and perpendicular to their plane, measuring their hydraulic properties in two directions are necessary for practical purposes.The permittivity is the water permeability perpendicular to the surface of the geotextile at cross-plane hydraulic conductivity, and the transmissivity, is the water permeability along the plane of the geotextilein-plane hydraulic conductivity[5].

## 1.3 Geotextile Permeability

The permeability of geotextiles can vary immensely, depending upon the construction of the fabric. In the case of nonwovens, that thickness, porosity and, any coefficient of permeability decrease with increasing normal pressure. Permittivity is used mostly when referring to cross-plane coefficient of permeability of geotextiles. Once permittivity is known, the flow capacity of the geotextile can be calculated for any given combination of hydraulic gradient and flow area. Permittivity is defined as the volumetric flow rate of water per unit area, per unit head, under laminar flow condition .As the flow of liquid is perpendicular to the plane of the geotextile, filtration refers to the cross plane hydraulic conductivity, or permittivity.

Geotextiles not only allow the passage of fluids in a direction that is perpendicular to the plane of the geotextile layer (like a filter), they can also function to provide planar drainage (flow parallel to the geotextile layer). This property is governed by transmissivity, which characterizes the ability to transmit water in-plane[7].

The influence of compressive stresses on the permeability of a geotextile to liquids in case of needle punched nonwoven geotextiles is considered. The coefficient of permeability to liquids is defined by Darcy's formula[3], [8].

$$q = kiA \text{ (Equation1)}$$

where:

q = Flow rate
k = Permeability
I = Hydraulic gradient: change in head divided by the length of the flow path (Δh/L)
A = Cross-sectional area

The permeability of candidate geotextiles can be obtained from the permittivity and thickness information using the following formula:

$$k_g = \psi_g t_g \text{(Equation 2)}$$

where:

kg= Geotextile permeability normal to the plane of the fabric
ψg= Geotextile permittivity, defined at the volumetric flow rate ofwater per unit cross-sectional area per unit head under laminar flow conditions, in the normal direction through a geotextile.
tg= Geotextile thickness
In-plane flow can be determined using the relationship:

$$q = k_P iA = k_P \, \mathrm{i}(Wt) \text{(Equation3)}$$

where:

q = Flow rate in the plane of the geotextile
$k_g$ = Hydraulic conductivity along the plane of the geotextile
i = Hydraulic gradient
A = Cross-sectional area
W = Width of the geotextile
t = Thickness of the geotextile
Characteristics of geotextile in-plane drainage are measured in terms of transmissivity, which is defined as:

$$\theta = k_P t \qquad \text{(Equation4)}$$

where:

Ɵ = Geotextile transmissivity in units of square meters per minute

$k_p$ = Geotextile permeability in the plane of the fabric

t = Geotextile thickness at a specified normal pressure

### 1.4 Packing density or porosity

Packing density of nonwoven web is defined as the ratio of the volume occupied by fibers to the whole volume of the web . Packing density is a crucial factor in determining the pore size, which controls fluid permeability.

The packing density can be calculated from the fabric basis weight, the fabric thickness, and the density of the polymer from which the fabric is made.

Packing density,

$\propto$ = total volume of fibres/totalvolume of the web

$$\propto\ = \frac{Vf}{V\,web} = \frac{Wf/\,pf}{tA} = \frac{Basis\ weight}{t\,p\,f} \text{(Equation5)}$$

where:

$Vf$ =volume of fibres

$V\,web$ =volume of the web

$W_f$=weight of fibres = weightof the web

$p\,f$ =fiber or polymer density

$t$ =thickness of the web

$A$ =area of the web

Porosity, ($\epsilon$) is the fraction of the void volume to the volume of the web,

$$\epsilon = 1 - \alpha \text{(Equation6)}$$

The packing density indicates the degree of porosity of the fabric where,porosity is the most important property that affects the absorption capacity of the material. Porosity is used to describe the porous structure of textile materials.It is defined as the amount of open spaces in the unit volume of fabric which depends generally on the fabric construction. It is a dimensionless quantity and can range between 0 and 1. The amount of porosity i.e., the volume fraction of voids within the fabric determines the capacity of a fabric to hold water.Porosity of geotextiles was calculated from the ratio of geotextile density and fibre density and expressed in percentage[3], [9], [10].

## II MATERIALS AND METHODS

In this study polyester (PET) and polypropylene (PP) needlepunched nonwovensof 500 g/m$^2$weight were produced. In addition, three needle penetration depthsof 8, 10 and 12 mm have been used to obtain three different thicknesses of geotextile for both PET and PP samples. Table (1) lists the constructional parameters of samples under study.Samples were testedfor thickness,permittivity and transmissivityaccording to standard testing methods ASTM-D1777, ASTM-D4491, ASTM-D4716 respectively. Furthermore, packing density of geotextiles was calculated from mass per unit area and thickness values.Moreover, porosity percentage of geotextiles were calculated from the ratio of geotextile packing density to fibre densitybased on polyester fibre density of 1.38 g/cm$^3$, and polypropylene fibre density of 0.91 g/cm$^3$.The results were evaluated statistically according to one-way variance analysis (ANOVA) in order to evaluate the significance of hydraulic properties of produced geotextiles.

**Table (1): Constructional parameters of geotextile samples under study.**

| Sample no. | Polymer Type | Mass per unit area (g/m$^2$) | needle penetration depths (mm) | Thickness (mm) |
|---|---|---|---|---|
| 1 | PET | 500 | 8 | 4.0 |
| 2 | | 500 | 10 | 4.9 |
| 3 | | 500 | 12 | 5.4 |
| 4 | PP | 500 | 8 | 4.59 |
| 5 | | 500 | 10 | 5.06 |
| 6 | | 500 | 12 | 5.56 |

## III RESULTS AND DISCUSSION

In this study, hydraulic properties of needle-punched nonwoven geotextiles are discussed.The geotextile permittivity and transmissivitywere determined using the equations presented above.Table (2)lists samples measured or calculated parameters.One-way variance analysis (ANOVA) was conducted to test results for samples as listed in Tables (3-8).

Table (2): Test results of produced geotextiles

| Sample no. | Polymer Type | Thickness (cm) | Permittivity (sec $^{-1}$) | Transmissivity (m$^2$/sec) | Packing density | Porosity % |
|---|---|---|---|---|---|---|
| 1 | PET | 0.4 | 4.7 | 0.78 | 0.091 | 91 |
| 2 | | 0.49 | 4. 1 | 0.79 | 0.073 | 92 |
| 3 | | 0.54 | 3.8 | 0.81 | 0.067 | 93 |
| 4 | PP | 0.459 | 3.9 | 0.82 | 0.118 | 88 |
| 5 | | 0.506 | 3.7 | 0.83 | 0.107 | 89 |
| 6 | | 0.556 | 3.5 | 0.86 | 0.097 | 90 |

### 3.1 Permittivity and Transmissivity

From Table (2) it can be observed that permittivity decreases when the thickness increasesfor both PET and PPsamples. This can be explained by the penetration depth used in the production of the samples as listed in Table (1). With the decrease of the penetration depth (8 mm)and mass per unit area remaining constantthe sample preserves to a great extent it layered structure which in turn leads to the easier passage of the liquid in the horizontal direction rather than the needed liquid movement in the perpendicular direction needed in the permittivity test and vice versa. Contrarily to permittivity results, the highest thickness samples for both PET and PP scored the highest transmissivity values (0.81 and 0.86 respectively). This can be explained by the higher ability to accommodating liquid resulting from increased length of passages formed inside the higher thickness samples which in turn imparts those samples improved liquid transmissivity when compared to lower thickness samples. Tables 3- 6 for ANOVA analysis show that the effect of the thicknesson permittivity and transmissivity ofnonwoven geotextilesfor both PET and PPare significant.

**Table (3): ANOVA for thickness and permittivity of PET nonwoven geotextiles**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 1.282222222 | 2 | *0.641111111* | 23.08 | 0.00152209 | 5.1432528 |
| Within Groups | 0.166666667 | 6 | 0.027777778 | | | |
| Total | 1.448888889 | 8 | | | | |

**Table 4: ANOVA for thickness and permittivity of PP nonwoven geotextiles**

| *Source of Variation* | *SS* | *Df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.202222222 | 2 | 0.101111111 | 7 | 0.027 | 5.1432528 |
| Within Groups | 0.086666667 | 6 | 0.014444444 | | | |
| Total | 0.288888889 | 8 | | | | |

**Table 5: ANOVA for thickness and transmissivity of PET nonwoven geotextiles**

| *Source of Variation* | *SS* | *Df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.001067 | 2 | 0.00053333 | 9.6 | 0.013497 | 5.143253 |
| Within Groups | 0.000333 | 6 | 5.5556E-05 | | | |
| Total | 0.0014 | 8 | | | | |

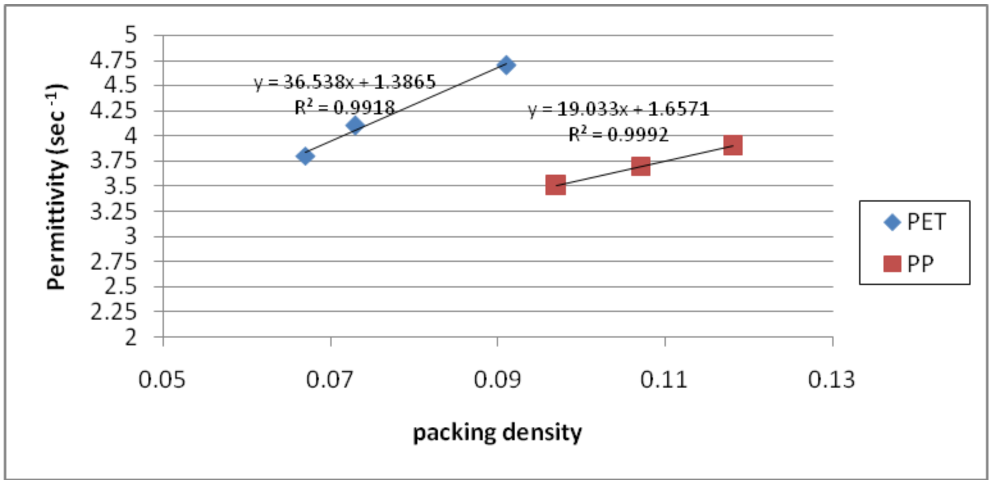
**Table 6: ANOVA for thickness and transmissivity of PP nonwoven geotextiles**

| *Source of Variation* | *SS* | *Df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.003356 | 2 | 0.00167778 | 13.72727 | 0.005769 | 5.143253 |
| Within Groups | 0.000733 | 6 | 0.00012222 | | | |
| Total | 0.004089 | 8 | | | | |

### 3.2 Packing density or porosity

From Table (2) it can be concluded that the increase in sample thickness leads to an increase in porosity for both PET and PP samples. This may be attributed to the increase of inter-fiber spaces due to the increase in sample volume because of the constant weight for all samples under study.

Moreover, it is obvious from Table (2) that packing density results are inversely proportional to thickness results and this is true for both PET and PP samples. This may be explained by reviewing sample thickness values and the formula governing the fabric and packing density as aforementioned in equations (5) where any increase in fabric thickness results in a decrease in fabric density. Accordingly, due to the constant weight of samples under study any increase in fabric thickness leads to decrease in packing density. And as thickness is inversely proportional with permittivity results and directly proportional with transmissivity results as explained earlier, then it can be deduced that packing density is directly proportional with permittivity resultsand inversely proportional with transmissivity results.Fig.(1)shows the linear correlation obtained between permittivity and the packing density for the nonwovens samples.



**Fig(1): Relationship between permittivity and the packing density**

As can be seen, a very good linear correlation between the permittivity and packing density for both PET and PP nonwoven geotextile samples.Fig.(2)presents the correlation between transmissivity and the packing density for the nonwovens samples.

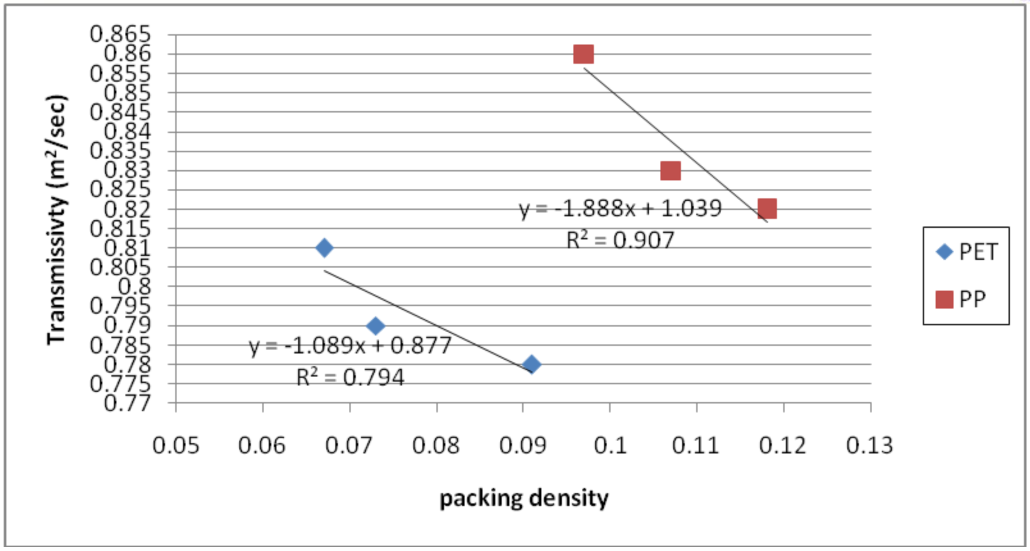


**Fig (2): Relationshipbetween transmissivity and the packing density**

As for the tansmissivity, an inverse linear correlation between transmissivityand packing density for both PET and PP nonwoven geotextile samples.

And as porosity was calculated from the formula (6), then it can be concluded that the relation between it and permittivity is inversely proportional. Accordingly, the relation between porosity and transmissivity is directly proportional. Finally, it can be concluded that results of packing density can be used as an indicator for both permittivity and transmissivity properties by only knowing the fabric thickness, mass per unit area and fiber density. Tables 7, 8 for ANOVA analysis show that the results ofnonwoven geotextiles packing densityfor both PET and PPare significant.

**Table (7): ANOVA for packing densityof PET nonwoven geotextiles**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.000916 | 2 | 0.000458 | 111.4324 | 1.8E-05 | 5.143253 |
| Within Groups | 2.47E-05 | 6 | 4.11E-06 | | | |
| Total | 0.000941 | 8 | | | | |

**Table (8): ANOVA for packing density of PP nonwoven geotextiles**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.000624 | 2 | 0.000312 | 122.9965 | 1.35E-05 | 5.143253 |
| Within Groups | 1.52E-05 | 6 | 2.54E-06 | | | |
| Total | 0.00064 | 8 | | | | |

## IV CONCLUSION

In this study hydraulic properties,namely permittivity and transmissivity, and structural parameters ofseveral needle punched nonwoven geotextiles wereinvestigated. The obtained results demonstrate the importance of packing density as an indicator for both permittivity and transmissivity properties of needle punchednonwoven geotextiles. It can be concluded from the experimental results that by increasing sample thickness,given that weight of sample is constant for both PET and PP samples, permittivity decreases and transmissivity increases.These results are in agreement with the results of packing density of the samples.Significant linear correlations between packing density of the nonwovens and these hydraulic properties have been found.Results thus eliminating the need for permittivity and transmissivity tests in case if there was a need for a quick method for knowing the approximate hydraulic properties of samples.

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