Temperature Correction for Water Permeability Determination of Geotextiles

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ABSTRACT: Since water permeability determination of geotextiles is mostly carried out at ambient temperature and not at the reference temperature, a correction factor based on the ratio of the viscosity of water at ambient test temperature and that at the reference temperature is considered. This correction factor was assumed for all flow conditions although, strictly, it only applies to laminar flow. Since the flow of water through most geotextiles does not occur under laminar conditions, the applied correction results in incorrect values of permeability. Permeability determinations of geotextiles illustrate that temperature correction for flow conditions, other than laminar, may result in a much larger deviation than no correction. A possible solution for the problem is the determination of water permeability within narrow limits around the reference temperature. This will undoubtedly require additional equipment. Experiments to detect the influence of the temperature have therefore been carried out and a procedure to correct water permeability values of geotextiles towards a reference temperature has been proposed. This correction holds for both the quadratic flow equation and the exponential equation, and is based on the application of the correction factor for the laminar part of the applied flow equation. The paper describes the experimental set-up and the results obtained, and gives evidence of the improved results if corrections are made according to the proposed procedure.

1 INTRODUCTION

Water permeability of geotextiles normal to the plane is one of the many parameters that can be used to characterize and to compare geotextiles. The water permeability determination of geotextiles is an index test which is mostly carried out at ambient temperature i.e. the temperature of the room where the tests are carried out. Specifications related to water permeability require the parameter at a given reference temperature, e.g. 10 or 20 °C. Since water viscosity depends on the temperature it can readily be accepted that a temperature correction needs be done when the test temperature differs from the reference temperature. The temperature correction is done in the same way, regardless whether laminar, transitory or turbulent flow occurs. Determinations of the water permeability parameter according to the existing specifications, are mostly carried out in the transitory flow zone while tests in the laminar flow zone are less common and in the turbulent flow zone rather exceptional. To reduce the effect of temperature correction on the water permeability parameter its determination can be carried out within narrow limits around the reference temperature but this will require an expensive conditioning equipment.

This paper deals with the influence of temperature on the water permeability parameter. It informs to which erroneous results a given temperature correction may lead if flow conditions are not taken into consideration and how a temperature correction has to be done according to the flow conditions. It is shown that a correct application of the temperature correction renders the purchase of a conditioning equipment superfluous.

2 THEORETICAL CONSIDERATIONS

The relationship between the head loss Δh and the filter velocity v can be expressed by the quadratic equation

$$\Delta h = av + bv^2 \qquad (1)$$

in which a and b are product-depending coefficients. At lower flow velocities the second term is negligible resulting in the laminar flow equation

$$\Delta h = av \tag{2}$$

while at higher flow velocities the first term is negligible resulting in the turbulent flow equation

$$\Delta h = bv^2 \tag{3}$$

The relationship between the head loss Δh and the filter velocity v can also be expressed by the exponential equation

$$\Delta h = cv^n \tag{4}$$

in which c is a product-depending coefficient while the exponent n is related to the flow conditions : (a) $n = 1$ for laminar flow ; (b) $n = 2$ for turbulent flow and (c) $1 < n < 2$ for transitory flow.

The unknown quantities a and b of the quadratic equation and c and n of the exponential equation can be determined from the best fit curve through the paired experimental data v and Δh. Values of Δh calculated for a given v or inversely of v calculated for a given Δh according to both equations do not differ significantly.

As the viscosity of a liquid influences its flow, a temperature correction will be necessary if experiments are carried out at a temperature T different from the reference temperature R. For laminar flow a linear relationship exists between the velocity at reference temperature, v_R, and the velocity at the measured temperature, v_T, namely

$$v_R = R_T v_T \tag{5}$$

in which $R_T = \eta_T/\eta_R$ is the temperature correction factor given by the ratio of the dynamic viscosity of water at reference temperature, η_R, and at the measured temperature, η_T. The dynamic viscosity η_T of water at a temperature T (°C) is, according to Poiseuille, given by

$$\eta_T = \frac{1.779}{1+0.03368T+0.00022099T^2} \quad \text{(mPa s)} \tag{6}$$

and the dimensionless correction factor R_T is obtained from

$$R_T = \frac{\eta_T}{\eta_R} = \frac{1+0.03368R+0.00022099R^2}{1+0.03368T+0.00022099T^2} \tag{7}$$

For $R = 20$ °C is

$$R_T = \frac{\eta_T}{\eta_{20}} = \frac{1.7620}{1+0.03368T+0.00022099T^2} \tag{8}$$

and for $R = 10$ °C is

$$R_T = \frac{\eta_T}{\eta_{10}} = \frac{1.3589}{1+0.03368T+0.00022099T^2} \tag{9}$$

Not considering the flow regime, the temperature correction for the quadratic flow equation results in

$$\Delta h = \frac{a}{R_T} v_R + \frac{b}{R_T^2} v_R^2 \tag{10}$$

and for the exponential flow equation in

$$\Delta h = c R_T^{-n} v_R^n \tag{11}$$

However, for turbulent flow conditions the viscosity does not excert an important influence on the water flow and should therefore not be considered. Since the quadratic equation consists of a fictive laminar and turbulent part, temperature correction of the laminar part may suffice for a correct temperature correction of the water permeability parameter. Hence the quadratic equation, after taking into account a certain reference temperature, can be written as

$$\Delta h = \frac{a}{R_T} v_R + b v_R^2 \tag{12}$$

For the exponential equation the splitting into a fictive laminar and turbulent part is not so evident but knowing that the temperature correction for laminar flow is R_T and that for turbulent flow no correction is required, the following exponential flow formula is applicable

$$\Delta h = c R_T^{n-2} v_R^n \tag{13}$$

3 PERMEABILITY APPARATUS

The apparatus to determine the water permeability parameters according to the constant head principle at the Research Station for Agricultural Engineering consists of an upward water reservoir with overflow to maintain a constant water level, a transparent tube of 60 mm inner diameter which contains the geotextile specimen, and an adjustable outlet which enables to determine the discharge for various head losses (Fig. 1). The water in the apparatus is recycled but changed each day. The water has normally the ambient temperature which may rise 2 to 3 °C within a period of 1 to 2 h due to circulation. The temperature is measured to an accuracy of 0.1 °C with a calibrated electronic thermometer in the upward water reservoir and at the outlet. Since no differences are observed between the two measurement places, the temperature of the water at the geotextile must be the same.

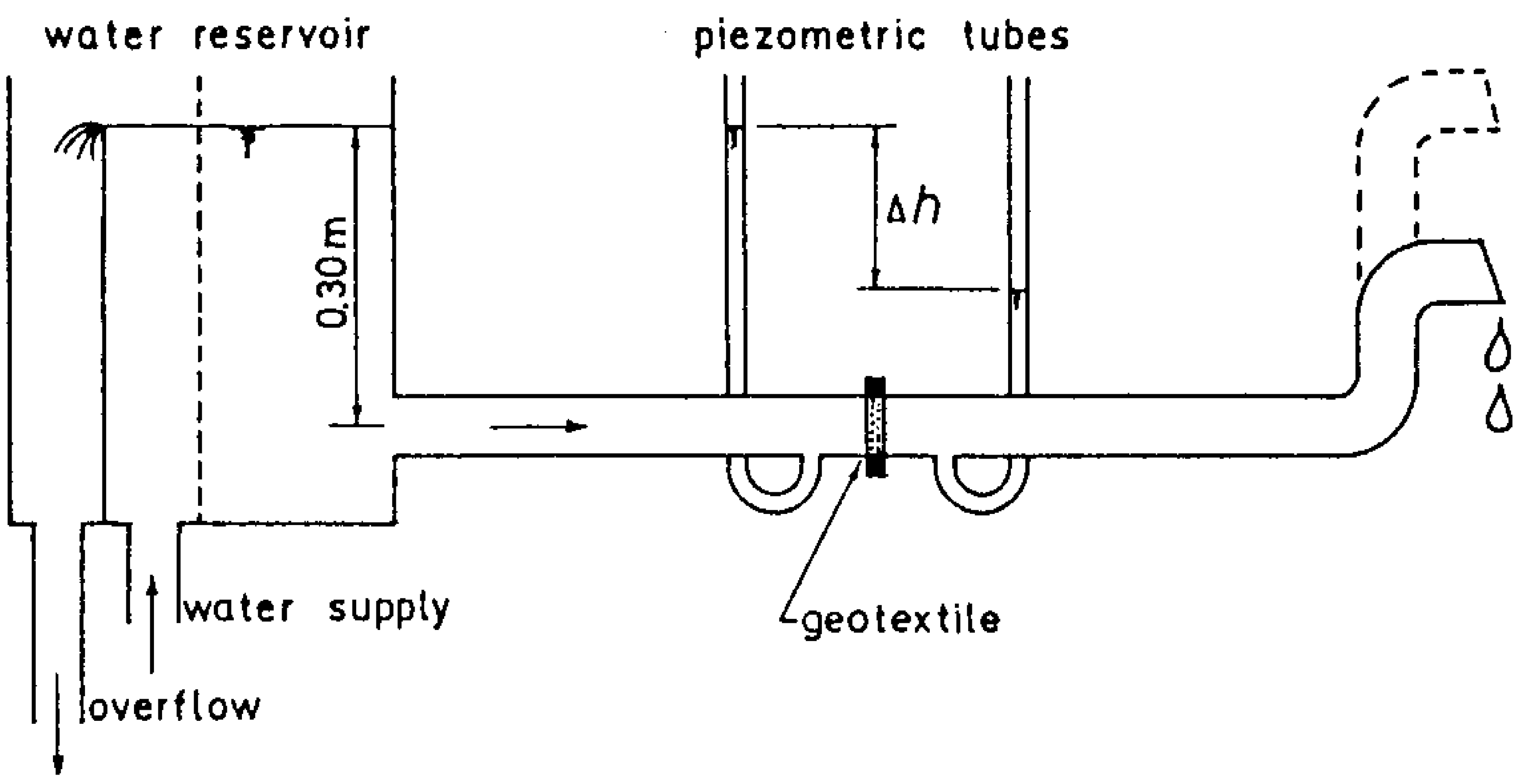

Figure 1 Scheme of the constant head water permeability apparatus.

To determine the effect of temperature on the water permeability parameter, experiments at constant reference temperature have to be carried out next to experiments at ambient temperature. This was realized by using a conditioning equipment which allows both to heat and to cool the water of the constant head permeameter. Using the conditioning equipment the water temperature variation was limited to 0.2 °C so that a preset temperature (reference temperature) could be maintained easily during the required period.

4 MATERIALS AND METHODS

To avoid possible influences of the used geotextiles, such as bending of the specimen and swelling of the fibres or yarns, two experiments were firstly carried out with 2.9 mm thick plexiglass plates having respectively 41 and 82 holes with a diameter of 1.5 mm. Furthermore a whole range of woven and nonwoven geotextiles have been used.

Measurements were carried out at about 10 and 20 °C. Both the quadratic and the exponential equation were determined at 10 as well as at 20 °C. Furthermore the temperature of 10 °C was considered as the reference temperature and both the quadratic and exponential equations obtained at 20 °C were subjected to a temperature correction to the reference temperature. Two different temperature corrections have been applied : (a) temperature correction for the total flow, and (b) temperature correction for the laminar part of the flow only.

As outlined in the theoretical considerations, the laminar temperature correction for the total flow cannot be correct when the flow is not fully laminar. Neglecting the temperature correction for turbulent flow, the temperature correction applied on the fictive laminar part of the flow seems to be more correct.

5 RESULTS AND DISCUSSION

The experimental results of the water permeability characteristics at 10 and 20 °C for both perforated plexiglass plates according to the quadratic equation are given in Fig. 2. The figure also contains the curves for both temperature corrections.

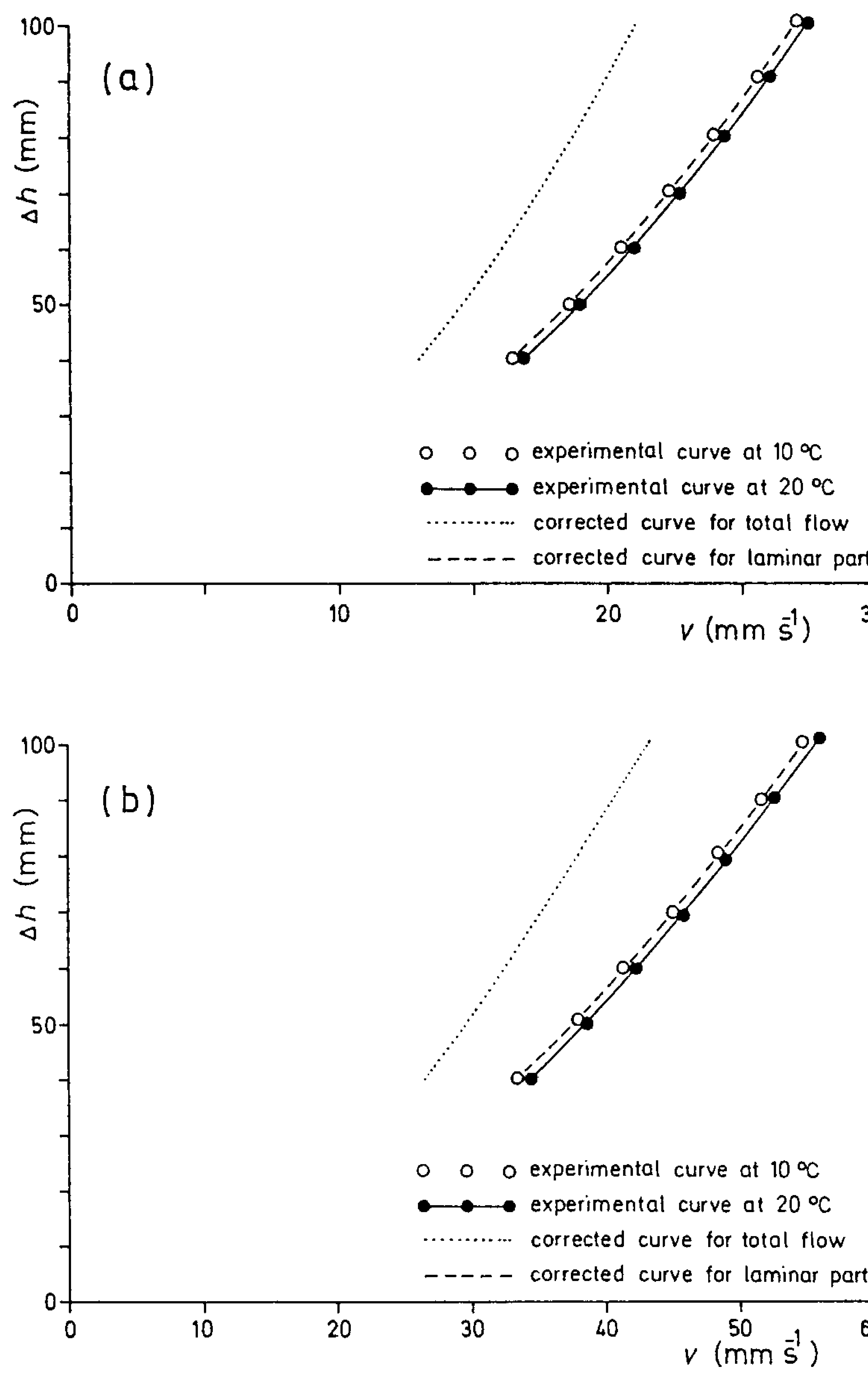

Figure 2 Water permeability curves for perforated plates with (a) 41 holes and (b) 82 holes of 1.5 mm diameter from experimental measurements and after temperature correction from 20 to 10 °C.

It can be derived that the experimental equations at 10 and 20 °C do not differ so much but that a temperature correction for the total flow gives completely faulty values while that for the laminar part of the flow can be considered as the correct way to do it. The small difference between the two curves at both temperatures and the large deviation as a result of the temperature correction for the total flow are attributed to that the transitory flow is nearer to turbulent than to laminar flow.

Fig. 3 gives the experimental and corrected results of the water permeability characteristics at 10 and 20 °C for a nonwoven geotextile. Due to that transitory flow in this case is nearer to laminar than to turbulent flow, the spacing between the experimental curves for 10 and 20 °C is much larger while the temperature correction for the total flow deviates much less compared to the previous case. Also here it is obvious that the correction of the laminar part of the flow results in smaller deviations than the correction of the total flow.

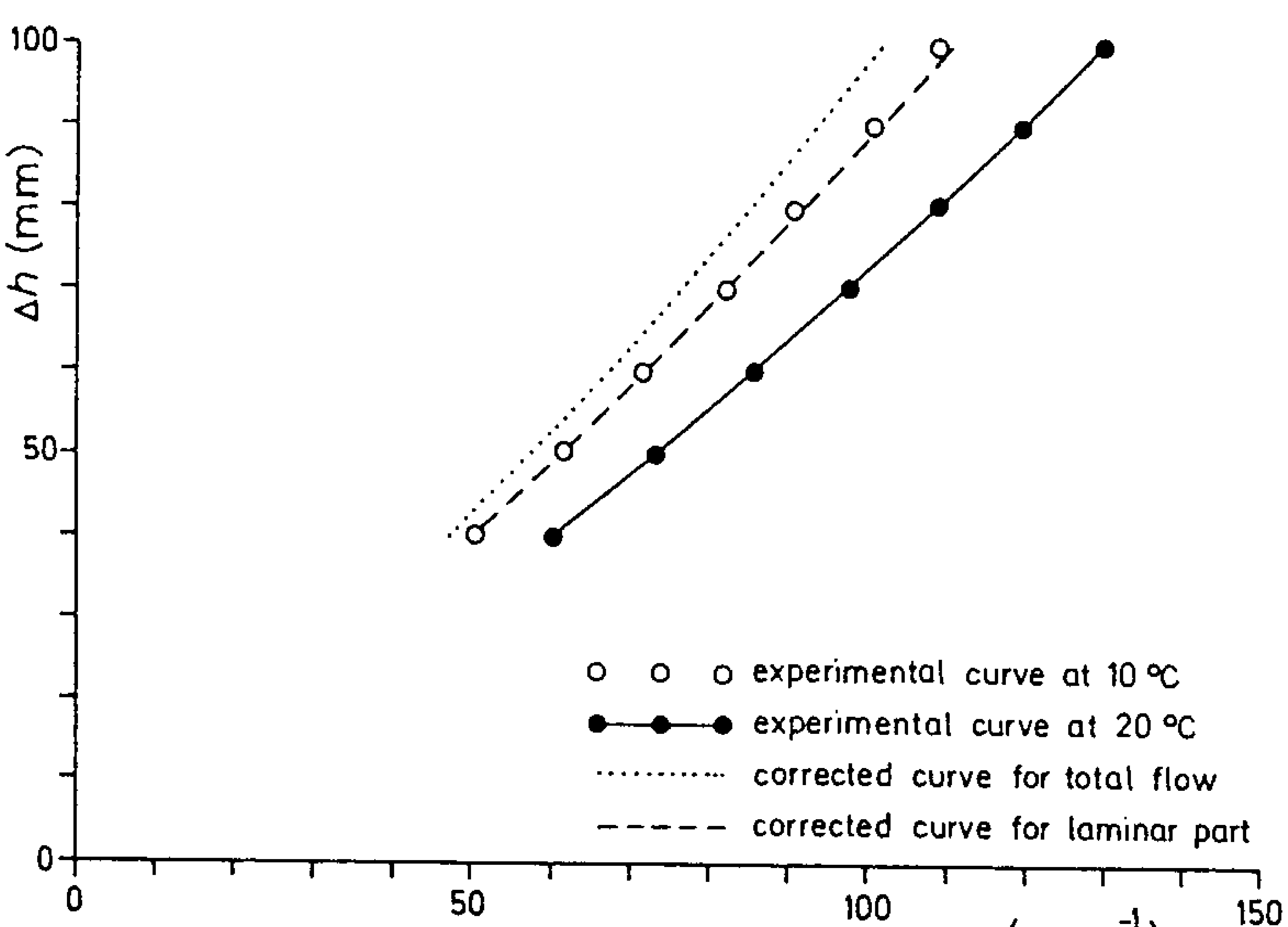

Figure 3 Water permeability curves for a nonwoven geotextile from experimental measurements and after temperature correction from 20 to 10 °C.

The experimental and corrected results of a transitory flow at about midway between the laminar and turbulent flow for a woven slit tape geotextile are given in Fig. 4. From this figure it can be seen that the experimental curves at 10 and 20 °C are nearer to each other with larger deviations for the correction of the total flow than for the laminar part of the flow.

Since the exponential equation has been obtained from the same experimental values and the temperature correction is done in the same way, the same results are obtained within very narrow limits.

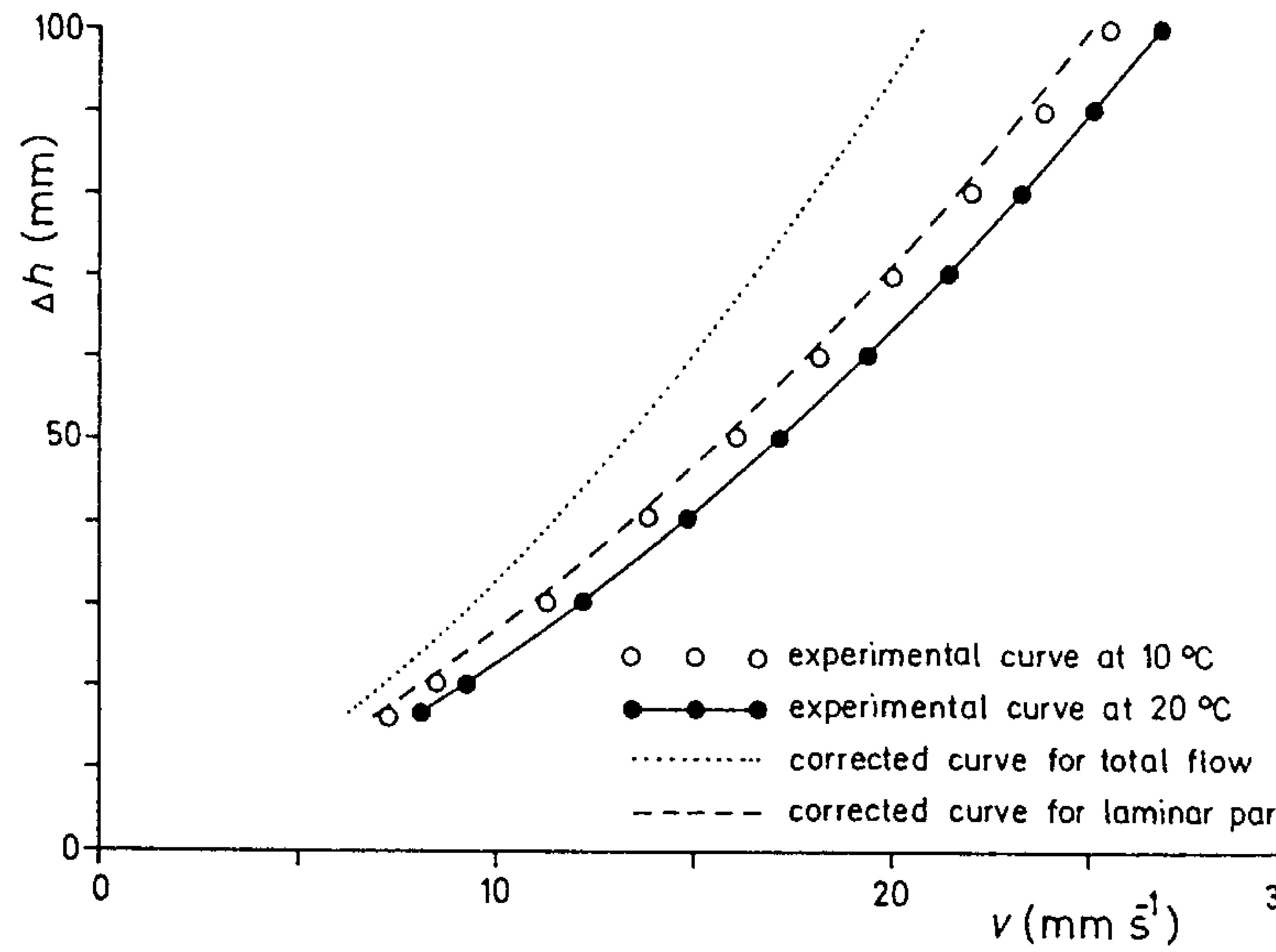

Figure 4 Water permeability curves for a woven slit tape geotextile from experimental measurements and after temperature correction from 20 to 10 °C.

6 CONCLUSIONS

From the experiments on the effect of temperature on the water permeability characteristics of geotextiles it can be concluded that the water permeability characteristics according to the exponential equation do not significantly differ from those of the quadratic equation and that both equations can be used with the same accuracy. If however the measuring temperature differs from the reference temperature, a temperature correction is necessary and the more the larger the temperature difference. Only a temperature correction of the fictive laminar part of the flow gives correct values for the permeability parameters. A temperature correction of the total flow is wrong as large deviations from the correct values result the more the transitory flow is nearer to the turbulent flow.