Modelling Wind Velocity Patterns for Windbreak Fence Design

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Introduction & Objectives

Windbreaks have been used for many years as a wind erosion control measure against losses of valuable loam and nutrients in agricultural land and dispersion of eroded particles and dust to nearby habitation in potentially risky areas [1]. The efficiency of windbreak fences in terms of wind speed reduction is determined by various factors, such as fence porosity, porosity distribution, fence height and wind velocity. If more than two fences are installed, the spacing between fences is also an important factor. Since reduction of wind speed by windbreak fence is a highly complicated aerodynamic process, airflow patterns around the fence can be predicted by the Navier-Stokes equation. The purposes of this study are to explain the relationships main design factors and windbreak effect by fences, and to introduces a straightforward model to predict wind speed reduction by single fence and multiple fence array according to screen porosity, fence height, fence location and wind speed for the effective and economical use of windbreak fences.

Materials & Methods

- Fence porosity measurement
- Wind tunnel test / References
- CFD simulations of single/multiple fences according to wind speed, fence porosities and heights
- Data generation
- Model validation
- Regression process
  - Equations for a single fence
  - Equations for multiple fences

Fence porosity measurement

- Pilot tubes
- Pitot tube
- Flow rate controller
- Blower
- Acrylic circular pipe (50 mm inner dia.)

Delta, p is the pressure loss caused by the screens, ps and pl are the pressures measured at two pilot tubes, ρ is the fluid density, g is the gravitational acceleration, j is the friction coefficient of the acrylic pipe, L is the length between two pilot tubes, D is the pipe diameter and u is the fluid velocity in the pipe.

\[\Delta p = \rho g (\frac{L}{D} \frac{u^2}{2})\]

Windtunnel test and validation

- Three sets of screens layers
- Two wind-speeds
- The wind speed reduction was measured at leeward distances of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8 and 1.0 m behind the fence

Computational Fluid Dynamics (CFD) simulation

- Ansys Fluent 6.3
- Atmospheric boundary condition [2]
- Fence model by the Darcy-Forchheimer equation.

Results

Validation of CFD simulation

Comparison with windtunnel tests

Comparison with references

Regression process

- PUV (percent of upcoming velocity) prediction for a single fence according to fence height (H), wind velocity (U) and fence screen layer (N)

(𝑖≤0) \( PUV(α) = \alpha \exp(-\frac{x}{H}) - e \exp(-d \frac{x}{H}) + e \)

\(a = c_1 N + c_2 U N^2 + c_3\)

\(b = c_4 N^3 + c_5 \ln(U) + c_6\)

\(c = c_7 N + c_8 U N^2 + c_9\)

\(d = c_{10} N^4 \times U N^3 + c_{11}\)

Regression coefficients calculated by a genetic algorithm

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
<th>P̂UV of single fences</th>
<th>P̂UV of triple fences</th>
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<tr>
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</tr>
<tr>
<td>C10</td>
<td>0.0000</td>
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</tbody>
</table>

- PUV prediction for a multiple fence according to the number of fences (k) and fence locations (i)

\[PUV^{(k)}(i) = \sum_{i=1}^{k} PUV_{Fence j=1} (x)\]

where \(V_{i-1}(d_j) = V_0 \times PUV_{Fence j=(i-1)}(d_j)\)

Application program for fence design

Equations of this study are simple and repetitive and thus can be solved by a simple program coded by Microsoft Visual Basic.

Conclusion

For design purposes, the developed model provides a straightforward procedure to predict the windbreak performance of a single as well as multiple fences. Even though this research still needs in situ validation, the results of this study can be a good starting point for designing windbreak fences in many areas, such as for agricultural and industrial uses, because they provide immediate understanding of the wind speed reduction according to various design factors.

References