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# The Effect of Volumetric Porosity on Roughness Element Drag

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Much attention has been given to understanding how the porosity of two dimensional structures affects the drag force exerted by boundary-layer flow on these flow obstructions. Porous structures such as wind breaks and fences are typically used to control the sedimentation of sand and snow particles or create micro-habitats in their lee. Vegetation in drylands also exerts control on sediment transport by wind due to aerodynamic effects and interaction with particles in transport. Recent research has also demonstrated that large spatial arrays of solid three dimensional roughness elements can be used to reduce sand transport to specified targets for control of wind erosion through the effect of drag partitioning and interaction of the moving sand with the large (>0.3 m high) roughness elements, but porous elements may improve the effectiveness of this approach. A thorough understanding of the role porosity plays in affecting the drag force on three-dimensional forms is lacking. To provide basic understanding of the relationship between the porosity of roughness elements and the force of drag exerted on them by fluid flow, we undertook a wind tunnel study that systematically altered the porosity of roughness elements of defined geometry (cubes, rectangular cylinders, and round cylinders) and measured the associated change in the drag force on the elements under similar Reynolds number conditions. The elements tested were of four basic forms: 1) same sized cubes with tubes of known diameter milled through them creating three volumetric porosity values and increasing connectivity between the tubes, 2) cubes and rectangular cylinders constructed of brass screen that nested within each other, and 3) round cylinders constructed of brass screen that nested within each other. The two-dimensional porosity, defined as the ratio of total surface area of the empty space to the solid surface area of the side of the element presented to the fluid flow was conserved at 0.519 for the cubes and 0.525 for the mesh forms. Results from the study indicate that as volumetric porosity increases, the force of drag on an element increases although the 2-dimensional porosity remains unchanged for the case of the cube forms. The mesh forms show a similar result that with increasing number of internal forms present, drag increases, but the drag curves are different, suggesting the kind of porosity has an effect on drag. An important scaling parameter that controls drag on the cubes is the permeability (K) of the element, which is a function of the diameter of the tubes and the porosity. K seems to be of lesser importance for controlling drag on the mesh forms. We hypothesize that the drag force data do not universally collapse as a function of permeability due to Reynolds number dependency on flow conditions within the elements that can be laminar, transitional, or turbulent even though flow exterior to the forms is fully turbulent. For the mesh forms, the greatest effect on drag occurs with the addition of the first internal form with subsequent additions showing very little additional effect.