Conductivity gain predictions for multiscale fibrous composites with interfacial thermal barrier resistance

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Abstract

Nanocomposites are heterogeneous media with two or more microstructural levels. For instance, a nano-level characterized by isolated nano-inclusions and a micro-level represented by the clusters resulting from aggregation processes. Our goal is to present a procedure to study the influence of this aggregation process and interfacial thermal resistance on the effective thermal conductivity. The procedure is based on the Reiterated Homogenization Method and consists of two stages. First, an effective intermediate thermal property is obtained by taking into account only the influence of the individual nano-inclusions in the matrix. Second, the final effective thermal coefficient ($\hat{k}_{RH}$) is calculated considering the clusters immersed in the intermediate effective medium derived in the first step. The conductivity gain (k_{gain}) is defined as the quotient ($\hat{k}_{RH}/\hat{k}_{CH}$) where $\hat{k}_{CH}$ is the effective thermal coefficient computed considering only one micro-structural level. The scheme is exemplified for 2-D square arrays of circular cylinders. The analytical formulas of the effective coefficient used in the calculations generalize other well known formulas reported in the literature. Finally, the effect of thermal conductivity gain is illustrated as a function of the Biot number, the quotient of the thermal conductivity, the fibers volume fraction and an aggregation parameter. The present contribution could be useful for nano-reinforced fibers applications and nanofluids. Furthermore, the present formulas can be used to assess numerical computations. An appendix is included showing similarities and differences between the obtained analytical formulas of effective coefficients, for different truncation orders, and those derived from the trifasic model.

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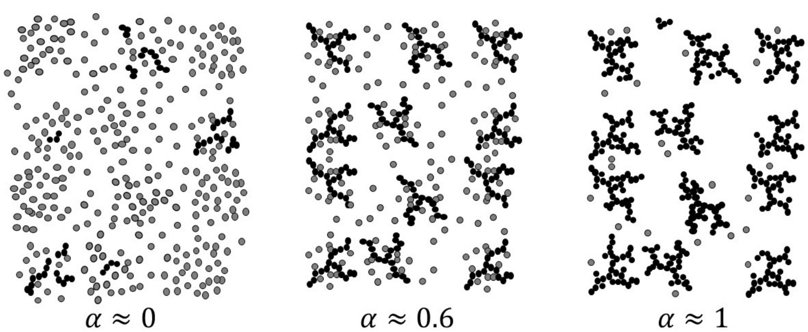

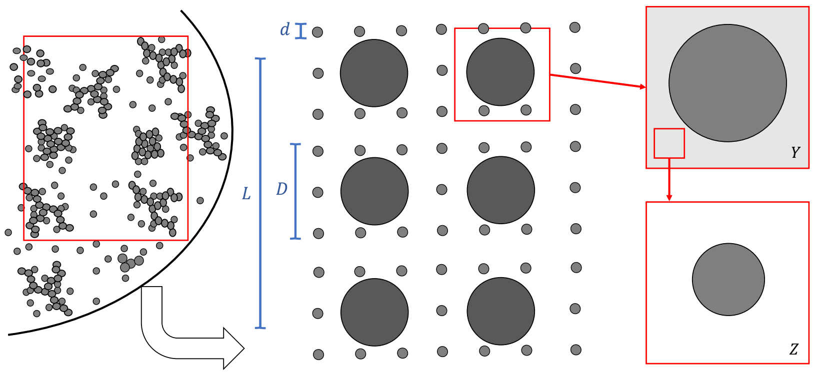

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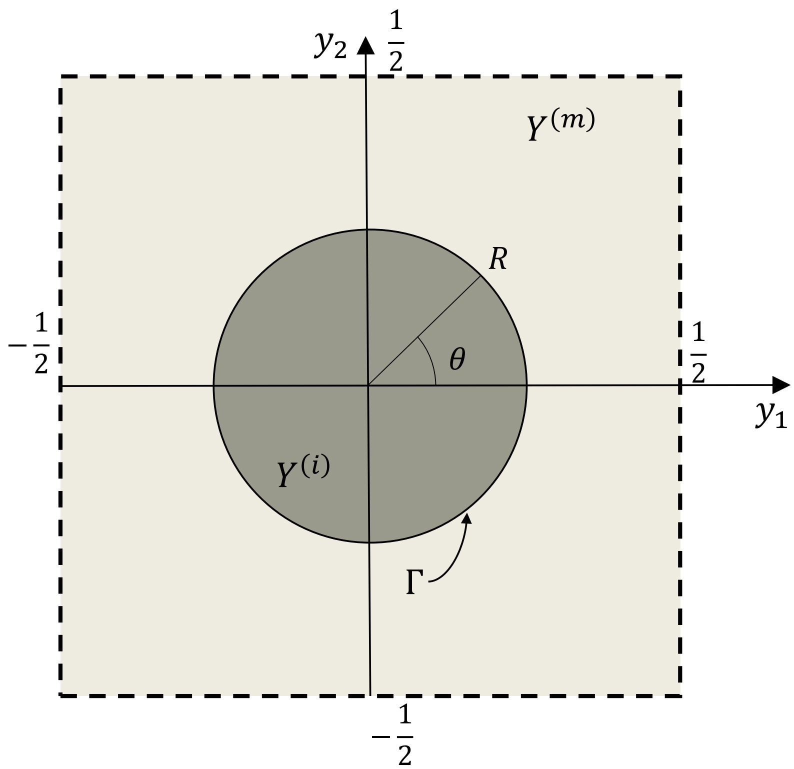

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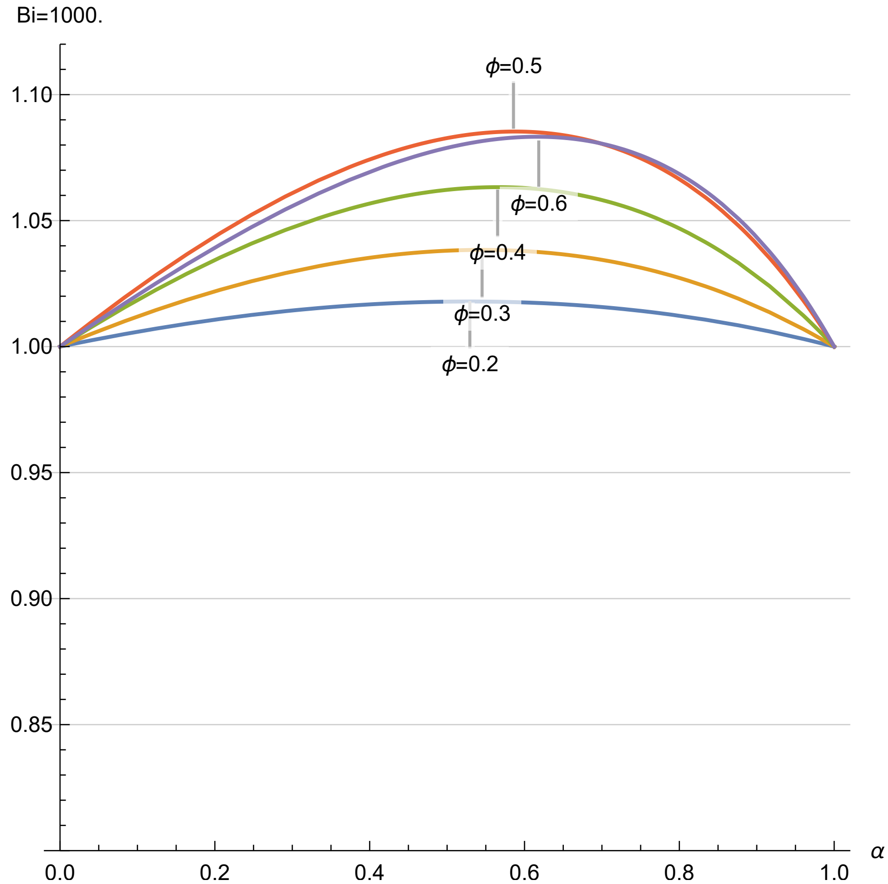
$\frac{1}{2}$
$Y^{(m)}$
R
θ
$-\frac{1}{2}$
$\frac{1}{2}$
y_1
$Y^{(i)}$
Γ
$-\frac{1}{2}$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0.85
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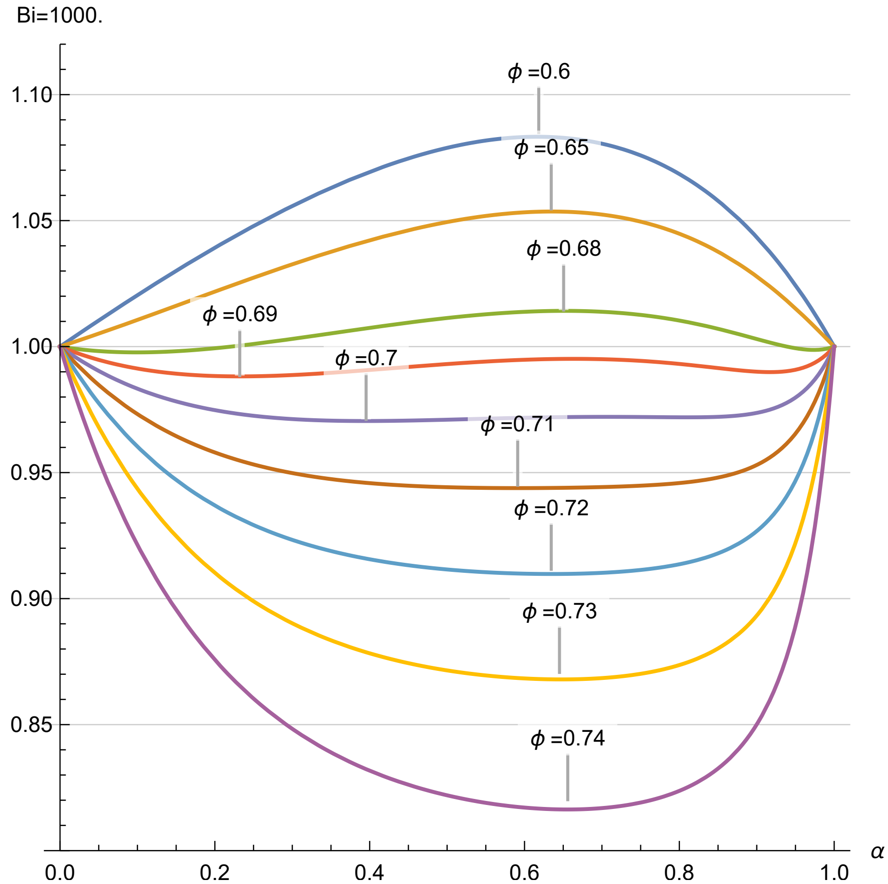
0.2
0.4
0.6
0.8
1.0
α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α
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ϕ =0.65
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ϕ =0.69
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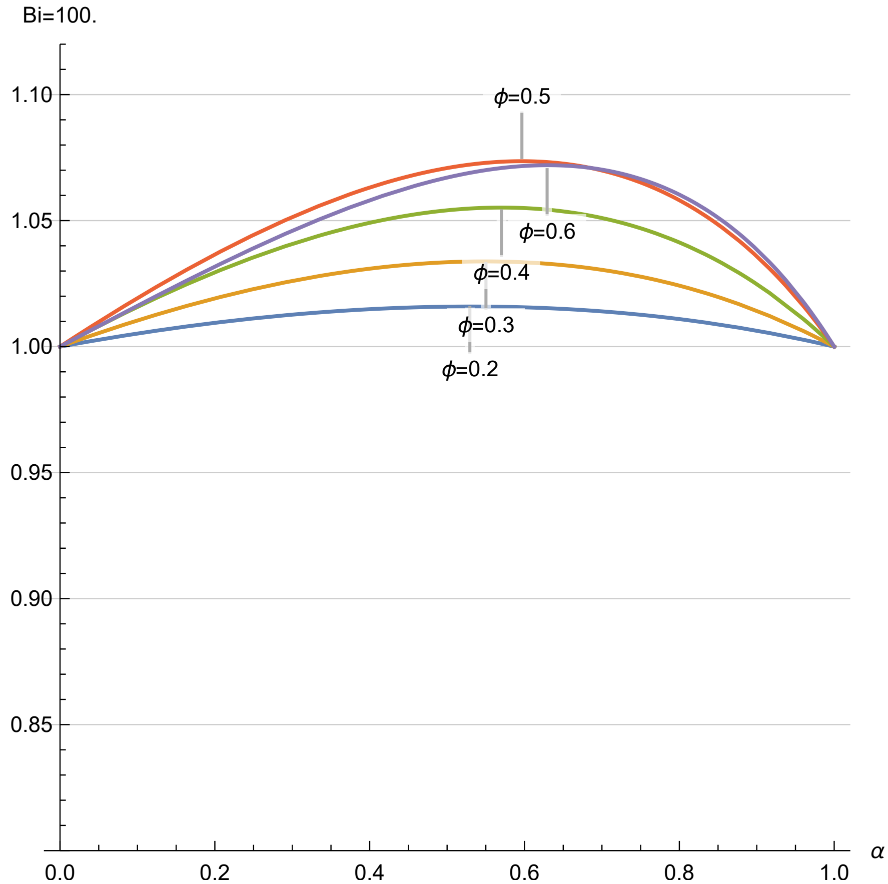
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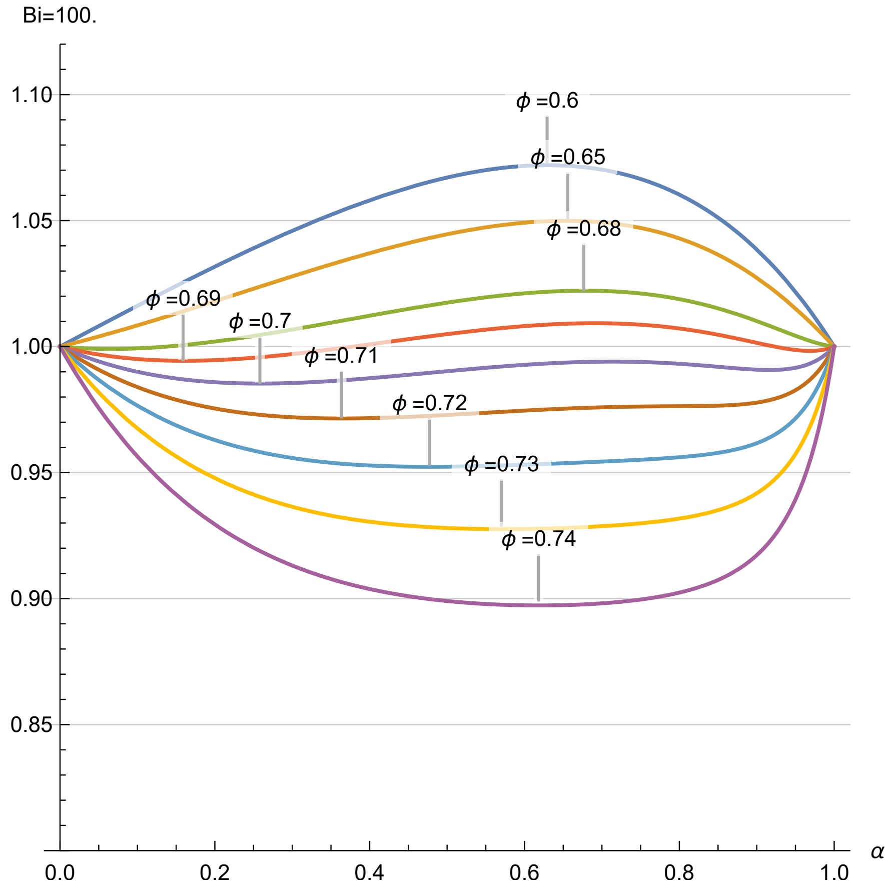
α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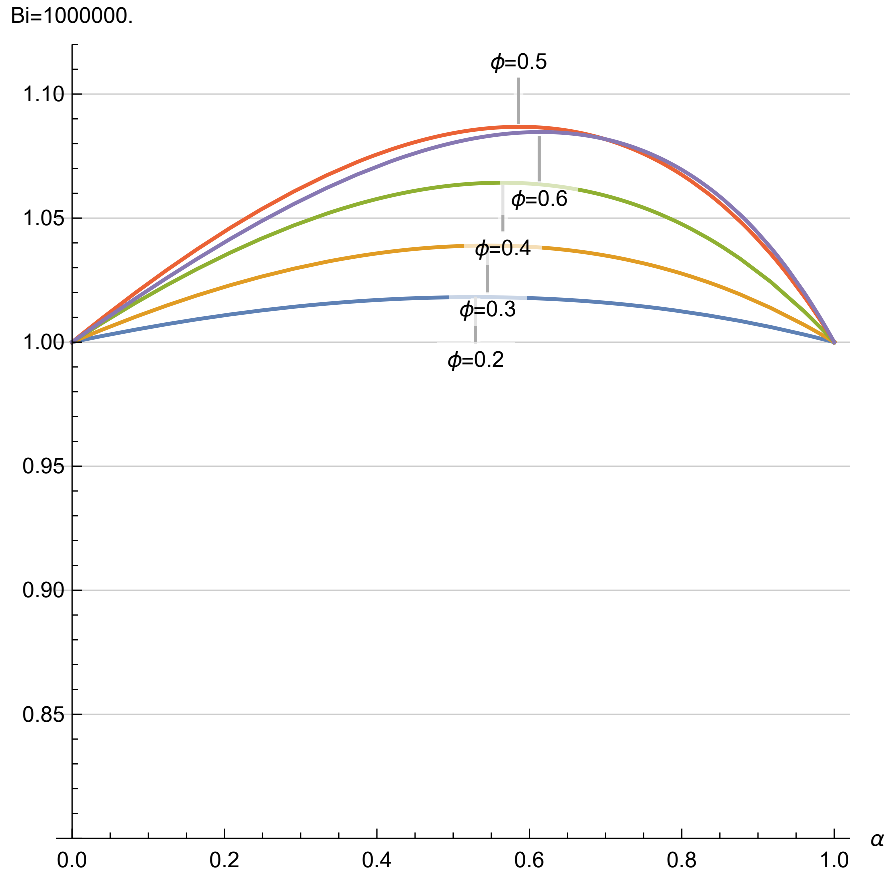
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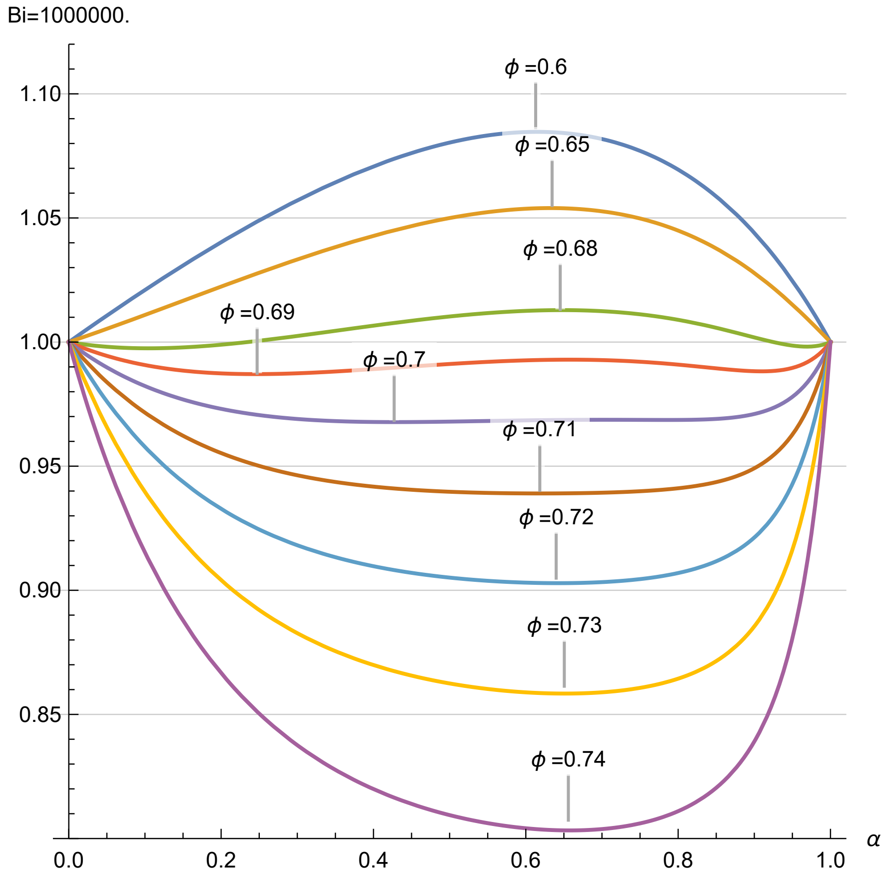
α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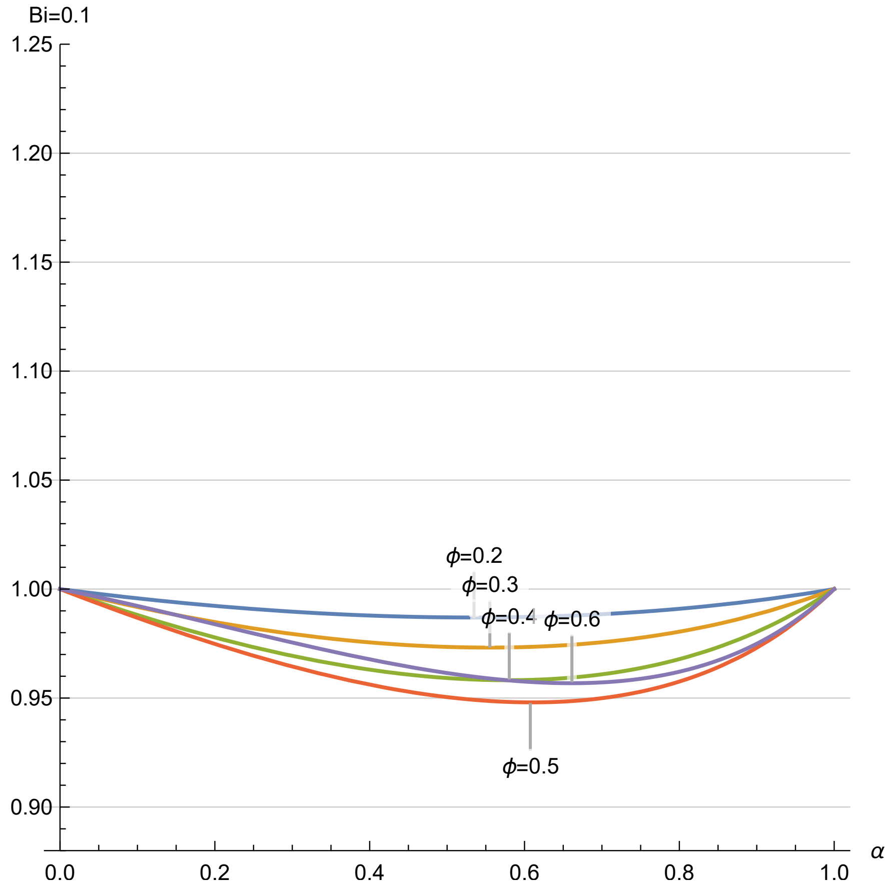
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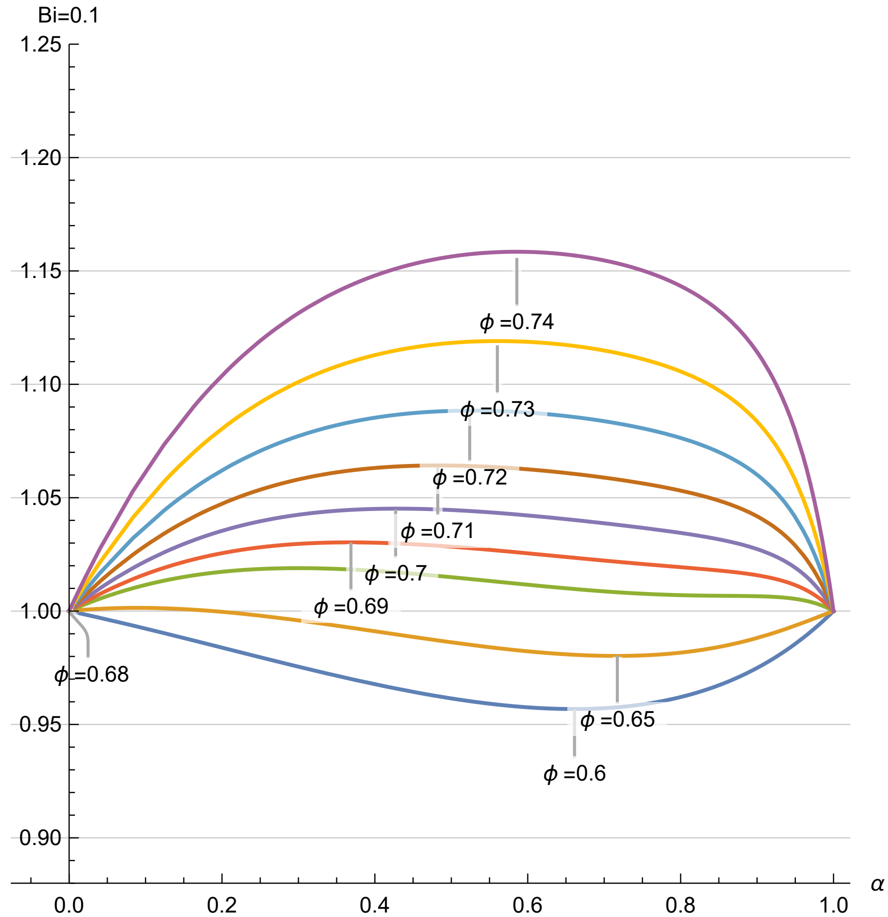
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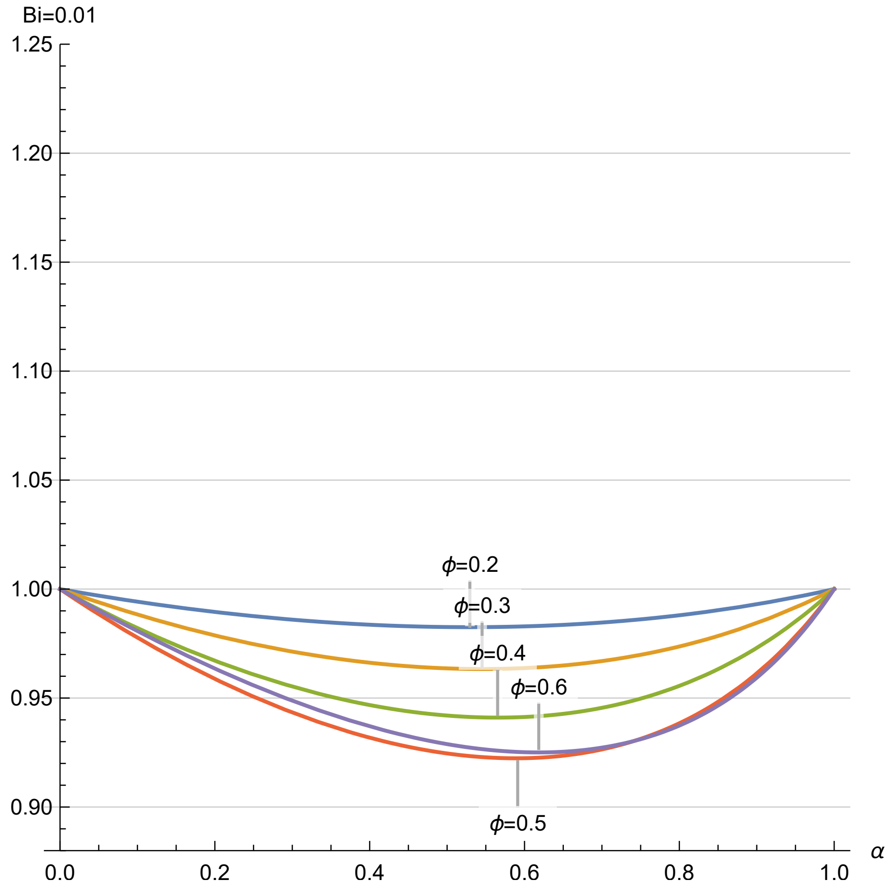
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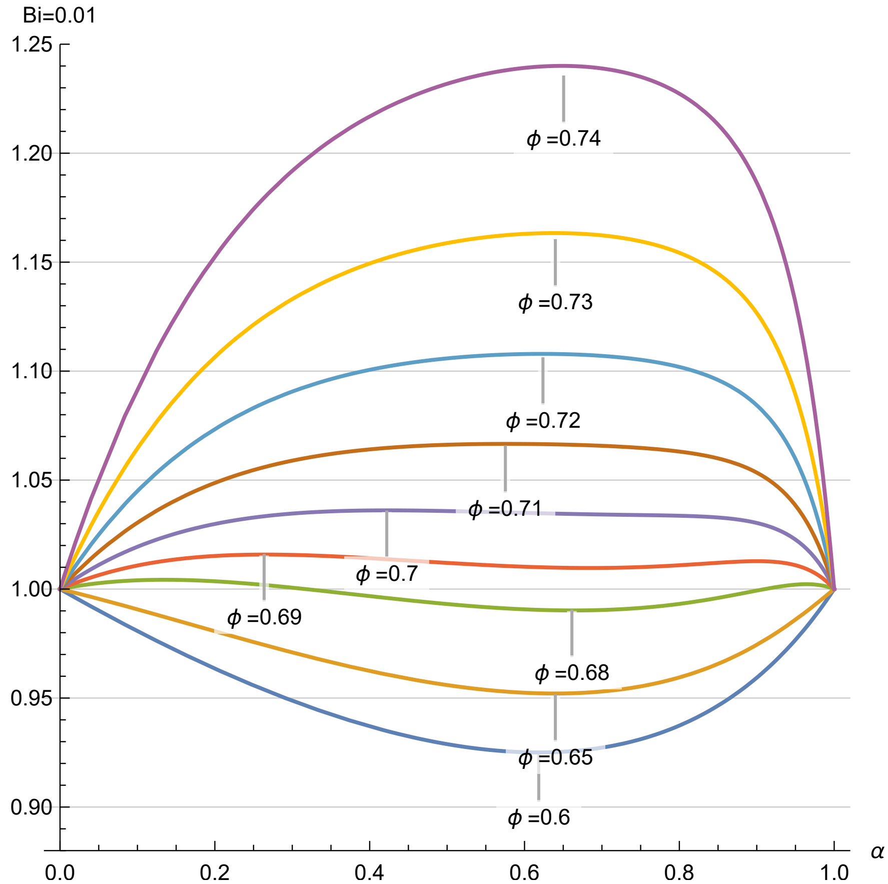
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0.8
1.0
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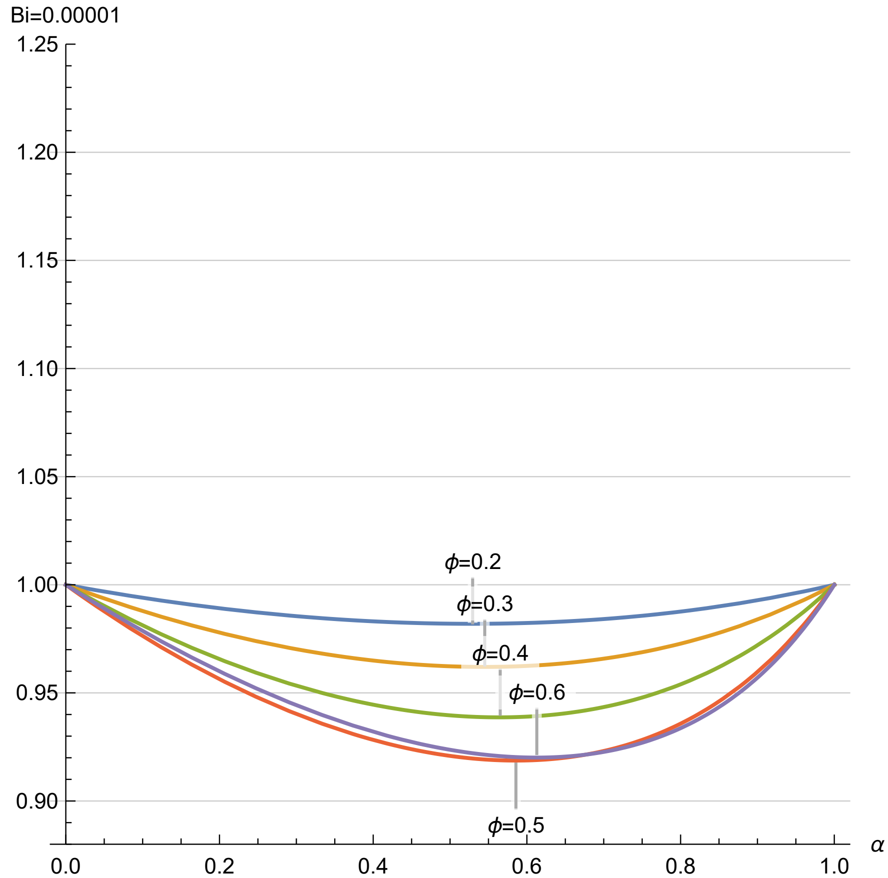
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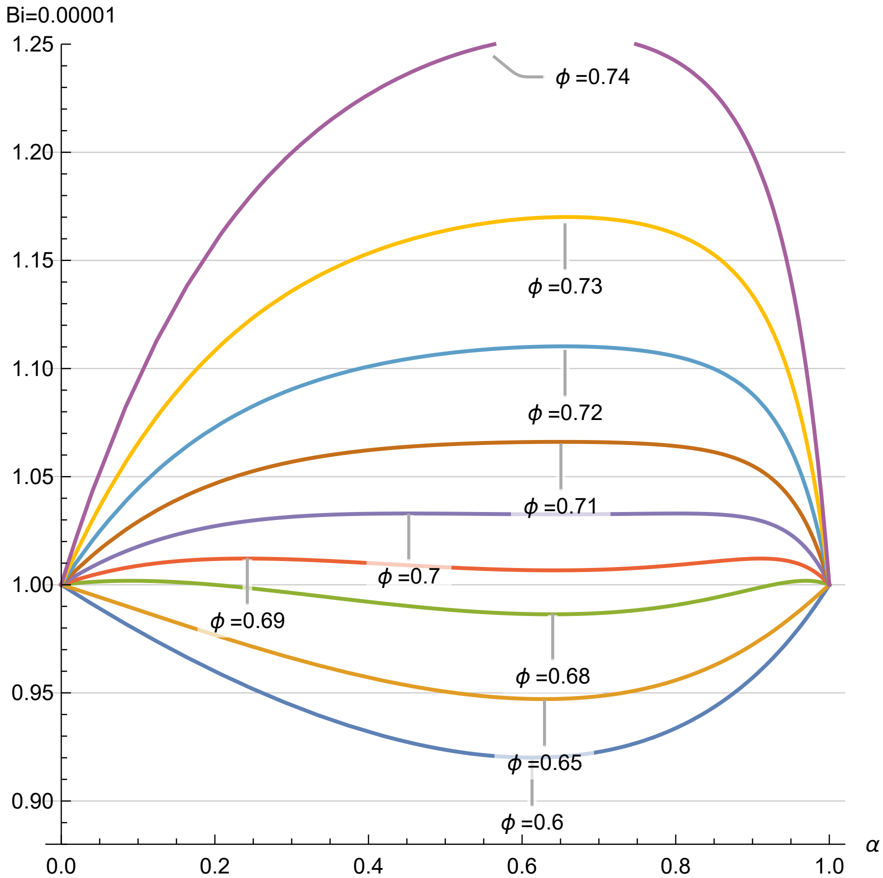
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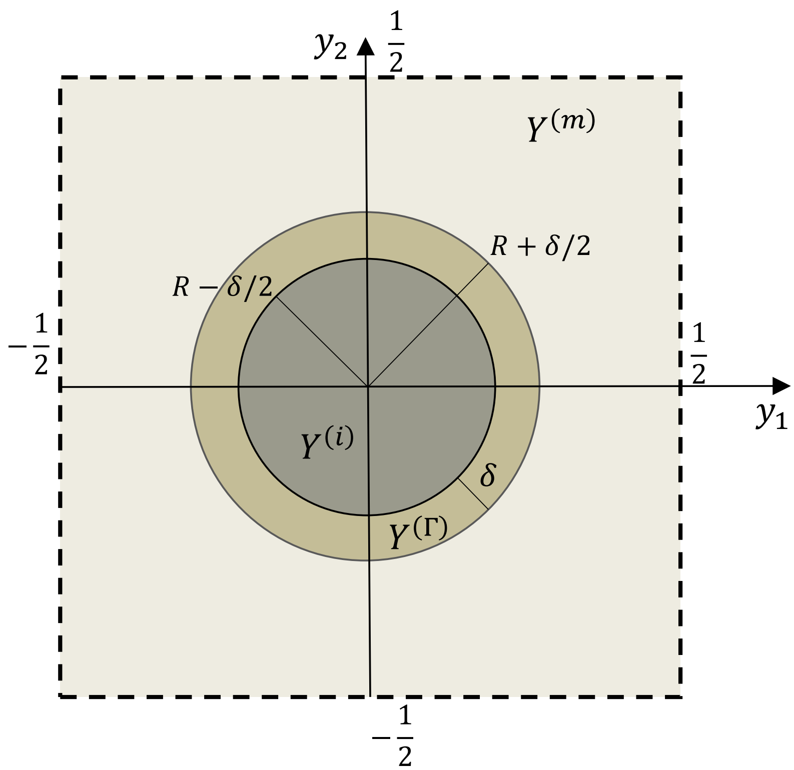
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$Y^{(m)}$
$R + \delta/2$
$R - \delta/2$
$-\frac{1}{2}$
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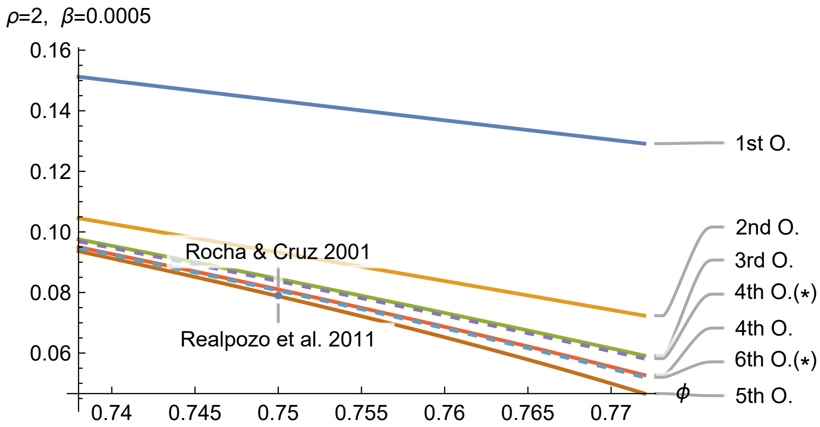
y_1
$Y^{(i)}$
δ
$Y^{(\Gamma)}$
$-\frac{1}{2}$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0.08
0.06
Rocha & Cruz 2001
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1st O.
2nd O.
3rd O.
4th O.(*)
4th O.
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5th O.
ϕ
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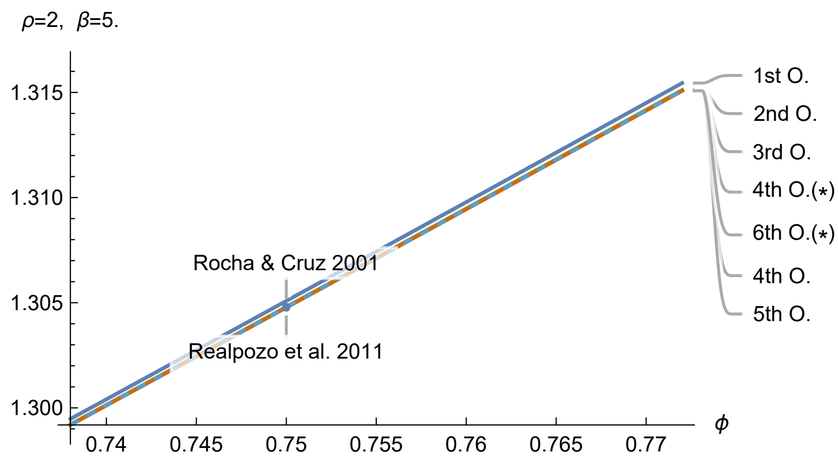
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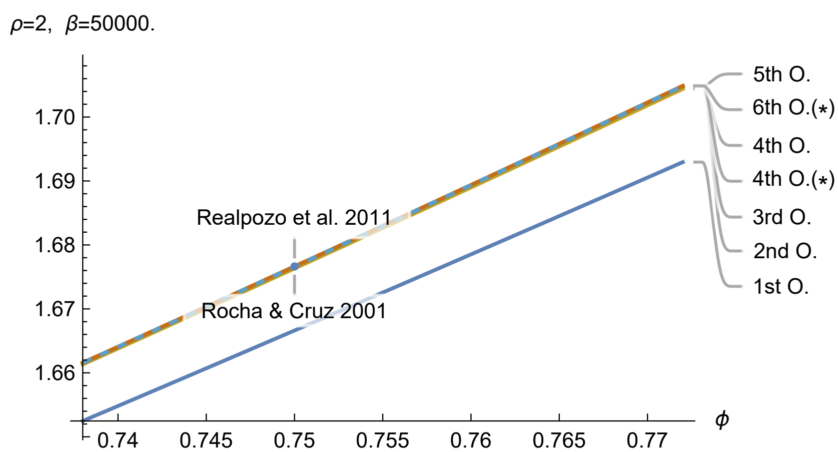
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Rocha & Cruz 2001
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0.765
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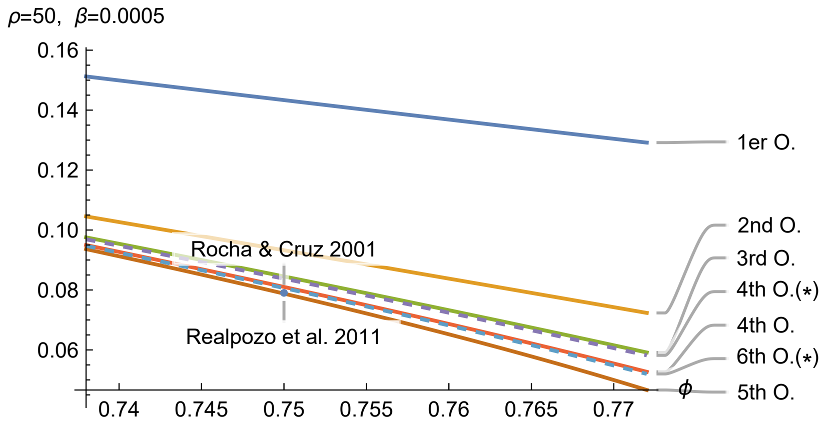
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ϕ
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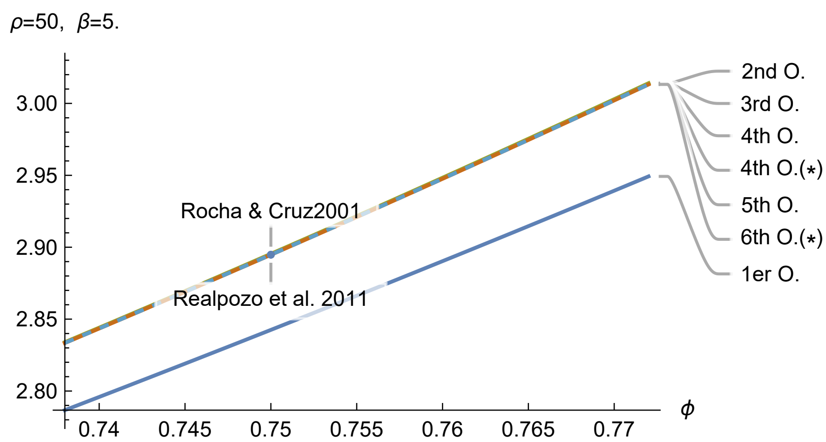
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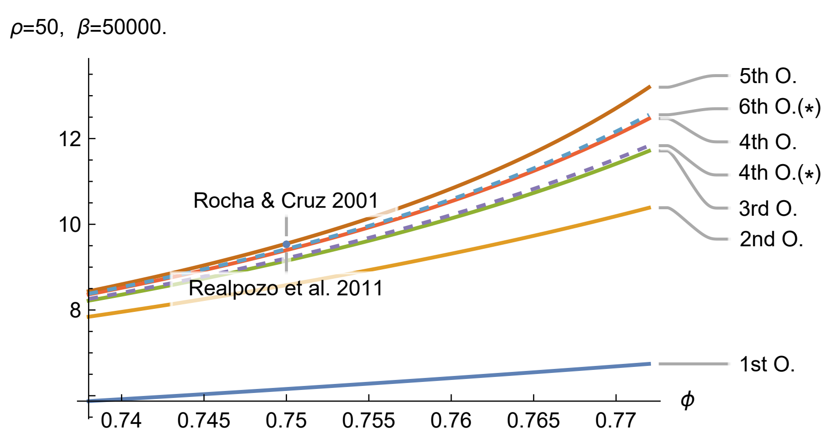
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1st O.