Predicting the Transformation of a Liquid Food Product within a Tubular Heat Exchanger

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Introduction: Continuous thermal processing is employed in industry as a step in the production of selected food products. The evolution of a simple liquid product (an aqueous suspension of starch granules) along an existing heat exchanger (Fig. 1) is here studied by 3-D modeling of fluid flow, heat transfer and transformation.

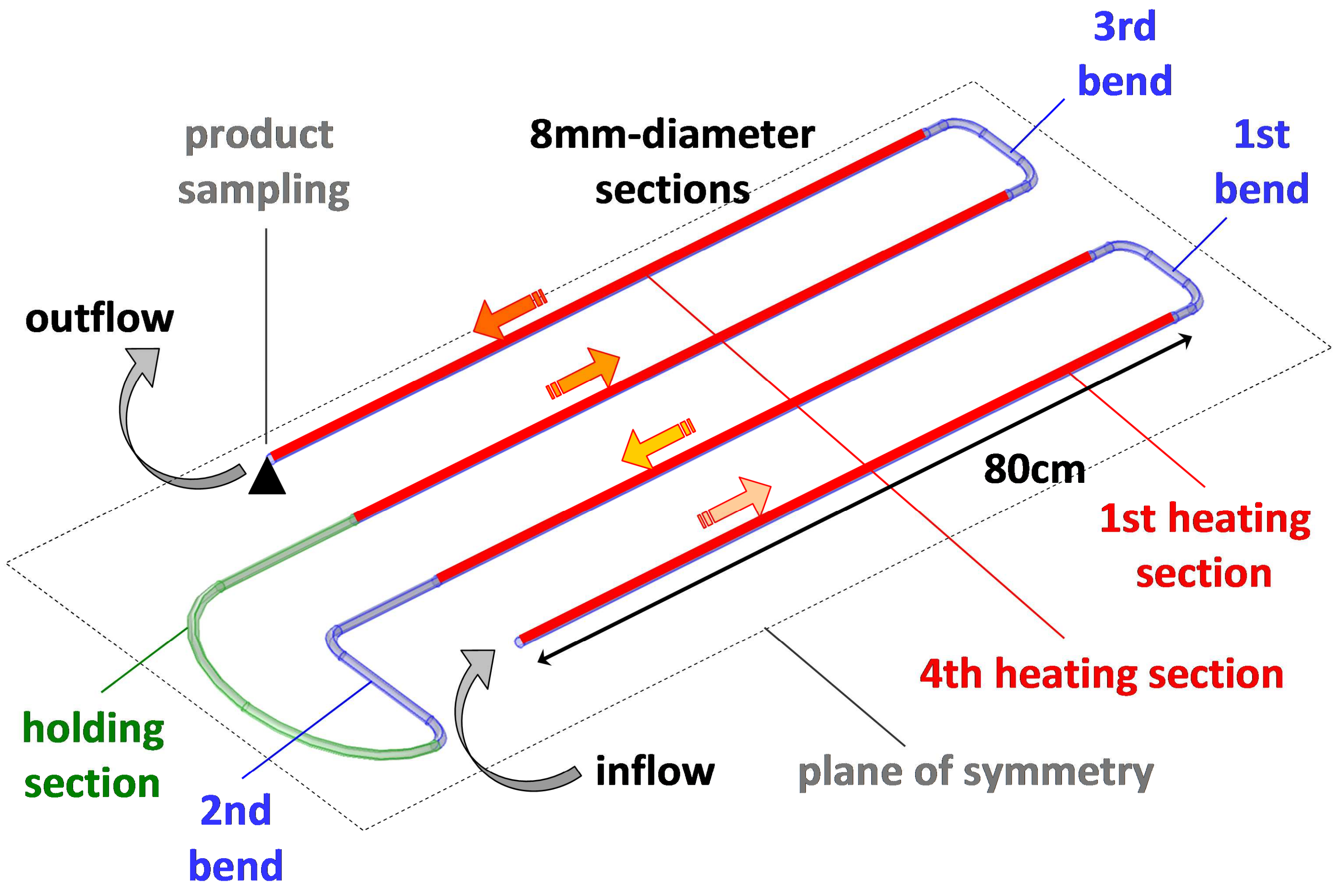

Figure 1. Schematic view of the heat exchanger

Computational Methods: Governing equations for the relevant phenomena are:

$$\vec{\nabla}.\left(\rho\,\vec{u}\right)=0$$

$$\rho\left(\vec{u}\cdot\vec{\nabla}\right)\vec{u}=\vec{\nabla}\cdot\left(-p\vec{I}+\eta\left(\vec{\nabla}\vec{u}+\left(\vec{\nabla}\vec{u}\right)^{T}\right)-\frac{2}{3}\eta\left(\vec{\nabla}\cdot\vec{u}\right)\vec{I}\right)$$

$$\rho C_P\left(\vec{u}\cdot\vec{\nabla}\right)T=\vec{\nabla}\cdot\left(\lambda\vec{\nabla}T\right)$$

$$\vec{u}\cdot\vec{\nabla}S=V\{T\}(1-S)^2+\vec{\nabla}\cdot\left(d_S\,\vec{\nabla}S\right)$$

$$S=\left(D-D_0\right)/\left(D_{MAX}-D_0\right)$$

V is the swelling kinetics rate of starch granules, and *D* is their mean volume diameter. Kinetics and rheological parameters come from laboratory work at batch scale. The mass concentration of starch is 3.42%.

The 3-D model takes into account the flow rate applied in running the heat exchanger, and assumes thermal insulation for bends and holding section. Fluid flow regime is laminar. The problem is solved under stationary conditions.

3-D computations are conducted in a four-node cluster (48 processors, 192 Gb RAM).

Results: 3-D modeling puts in evidence the role played by curved tubes (bends) situated between successive heating sections. They operate in mixing the liquid product (Fig. 2).

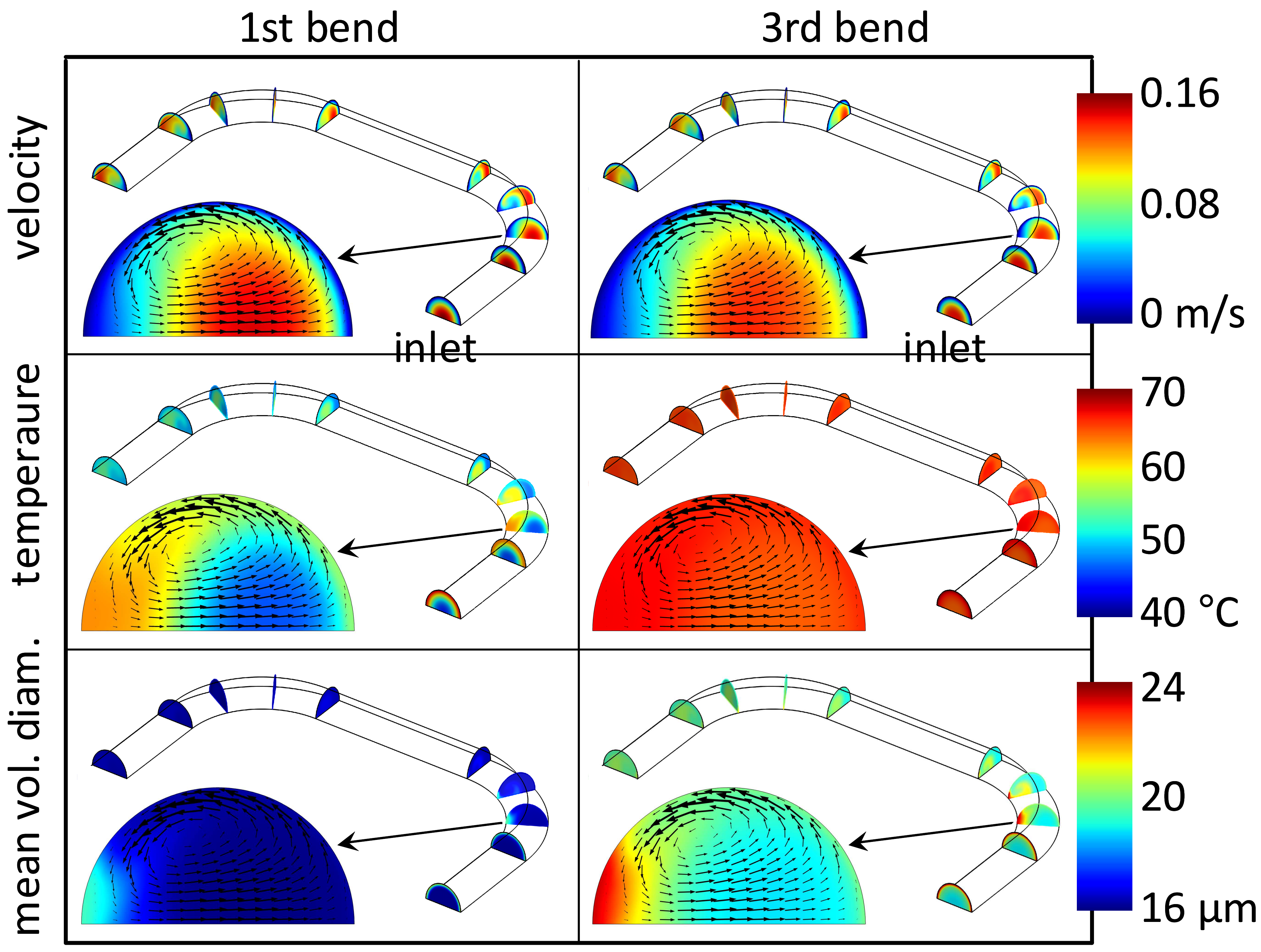

Figure 2. Results in the 1st and 3rd bends; the mean volume diameter of starch granules is larger in the 3rd bend

	mean volume diameter (*D*)	increase from initial value (D_0 = 16.3 µm)
observation (three samplings)	mean = 23.7 µm st. dev. = 0.4 µm	7.4 µm
1D approach (plug-flow)	21.5 µm	5.2 µm (–30%)
2D modeling (full mixing in the bends)	25.4 µm	9.1 µm (+23%)
2D modeling (no mixing in the bends)	24.0 µm	7.7 µm (+4%)
3D modeling	24.3 µm	8.0 µm (+8%)

Table. Assessment of mean volume diameter predictions at the 4th heating section's outlet (see Fig. 1)

Conclusion: While being more realistic than results reached from simpler approaches, 3-D predictions of the transformation state indicate the need for further efforts in representing the product kinetics.

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