Approximation of the Flow Field in Electrochemical Machining Incorporating Pressure Drop Calculation

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Introduction

- Regarded electrochemical machining (ECM) process for machining internal geometries shown in **Figure 1**
- For process design in ECM material removal simulation models with low computational costs required
- One effective approach: approximate fluid dynamics as two-phase potential flow of electrolyte and gas bubbles
- Due to model assumptions of potential flow, pressure drop not inherently described
- Objective of this work: develop submodel for approximation of pressure drop in ECM

Theory

- Total pressure regarded as a field variable calculated using the PDE

$$-\left(\frac{\vec{u}}{|\vec{u}|}\right)\cdot\nabla p_{\mathrm{tot}} - \nabla\cdot(s_{\mathrm{D}}\,\nabla p_{\mathrm{tot}}) = f(S,\bar{\varrho},\bar{u})$$

- At outlet boundary set $p_{\mathrm{tot}} = p_{\mathrm{out}}$
- Diffusion coefficient s_{D} to attain numerical stability
- Source term f as function of local working distance S and flow cross-section averages of density ϱ and flow velocity magnitude $u = |\vec{u}|$
- Working distance and flow cross-section averages calculated with additional PDEs using normed auxiliary vector field $\vec{v}_\perp$

Calculation of working distance and cross-section averages	
Working distance S	**Cross-section average $\bar{X}$ of X**
$S = S_{\mathrm{A}} + S_{\mathrm{C}}$ $\vec{v}_\perp\cdot\nabla S_{\mathrm{A}} - \nabla\cdot(s_{\mathrm{D}}\,\nabla S_{\mathrm{A}}) = 1$ $-\vec{v}_\perp\cdot\nabla S_{\mathrm{C}} - \nabla\cdot(s_{\mathrm{D}}\,\nabla S_{\mathrm{C}}) = 1$	$\bar{X} := \dfrac{X_{\mathrm{A}} + X_{\mathrm{C}}}{S}$ $\vec{v}_\perp\cdot\nabla X_{\mathrm{A}} - \nabla\cdot(s_{\mathrm{D}}\,\nabla X_{\mathrm{A}}) = X$ $-\vec{v}_\perp\cdot\nabla X_{\mathrm{C}} - \nabla\cdot(s_{\mathrm{D}}\,\nabla X_{\mathrm{C}}) = X$
At anode boundary: $S_{\mathrm{A}} = 0$ At cathode boundary: $S_{\mathrm{C}} = 0$	At anode boundary: $X_{\mathrm{A}} = 0$ At cathode boundary: $X_{\mathrm{C}} = 0$
Remaining boundaries: Zero diffusive flux	

- Auxiliary vector field $\vec{v}_\perp$ parallel to flow cross-section (**Figure 2**)

Results

- 2D-axisymmetric simulation of material removal in ECM; electrolyte conductivity based on local temperature and gas volume concentration
- Gas volume concentration influenced by pressure field; pressure field (**Figure 3**) calculated using developed submodel
- Calculation of auxiliary quantities, like cross-section average of flow velocity magnitude shown in **Figure 4** compared to local flow velocity

Conclusions

- Model is able to describe influence of changes in process parameters and geometry on pressure field and thus on hydrogen volume fraction, effective electrical conductivity and material removal
- Computationally efficient tool for ECM process design

Acknowledgements

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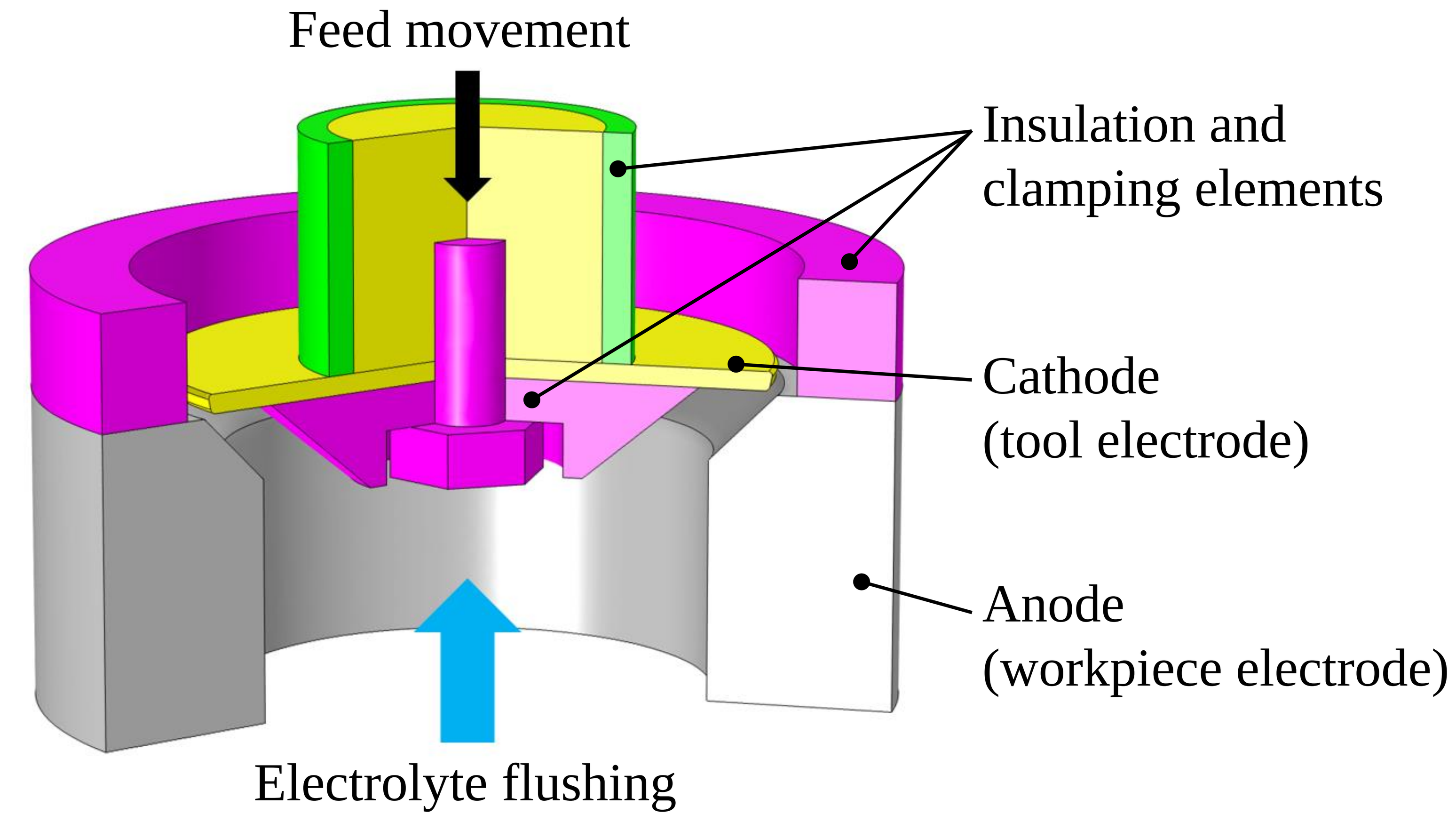

Figure 1. Machining concept of regarded electrochemical machining process

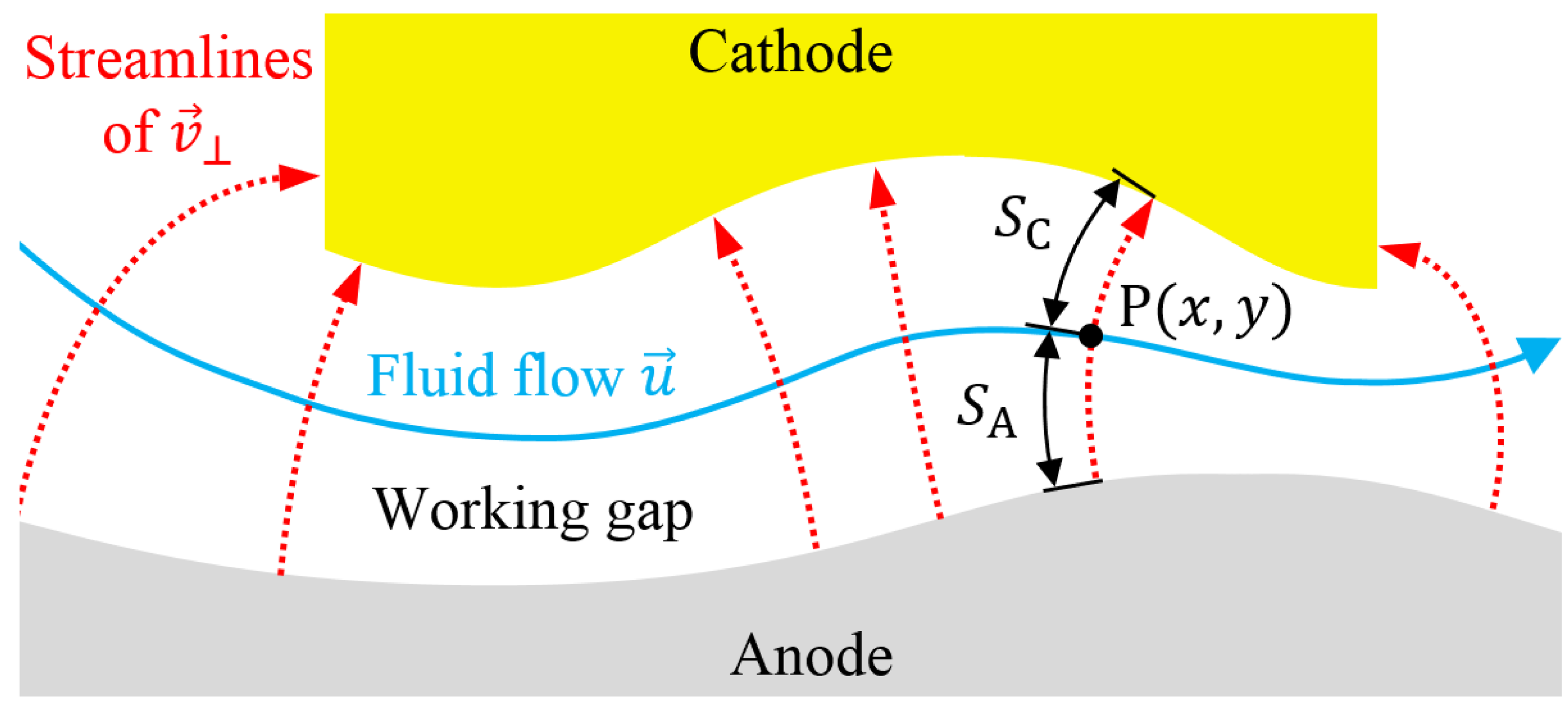

Figure 2. Working distance $S = S_{\mathrm{A}} + S_{\mathrm{C}}$ in arbitrary point P as length of the corresponding streamline of $\vec{v}_\perp$ for exemplary geometry

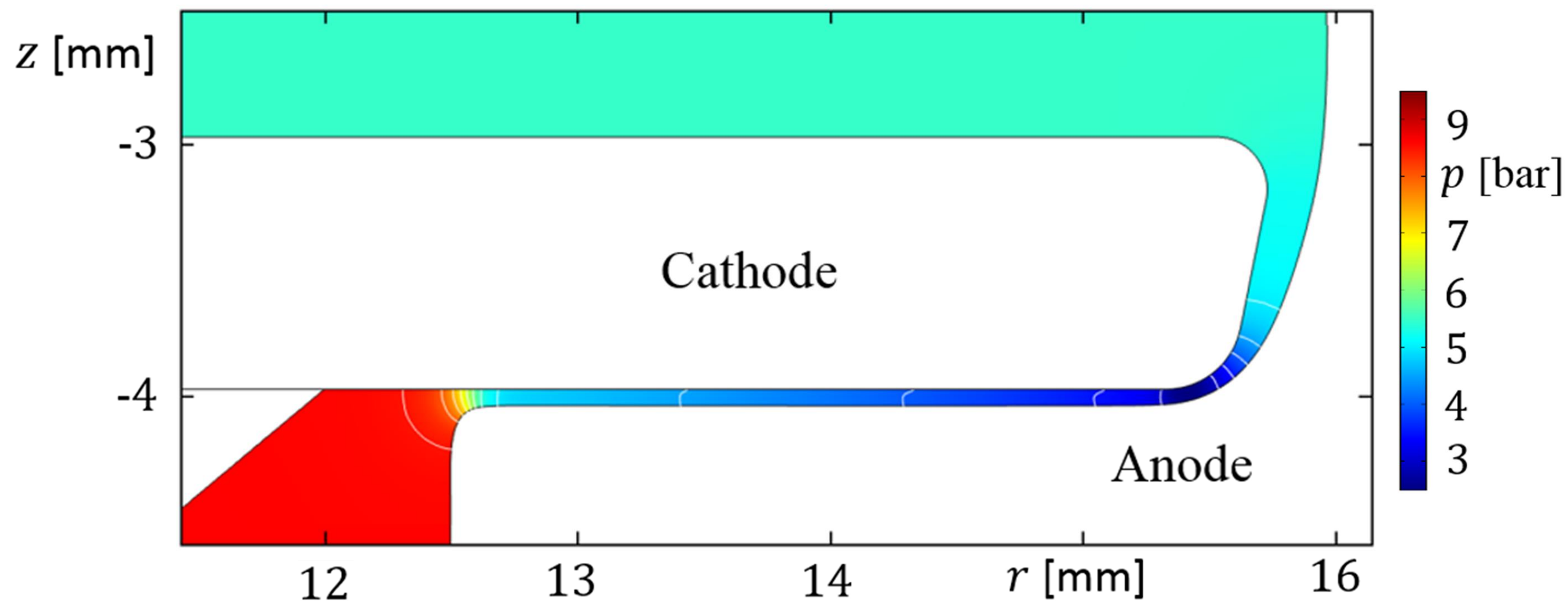

Figure 3. Static pressure p computed using Bernoulli's equation

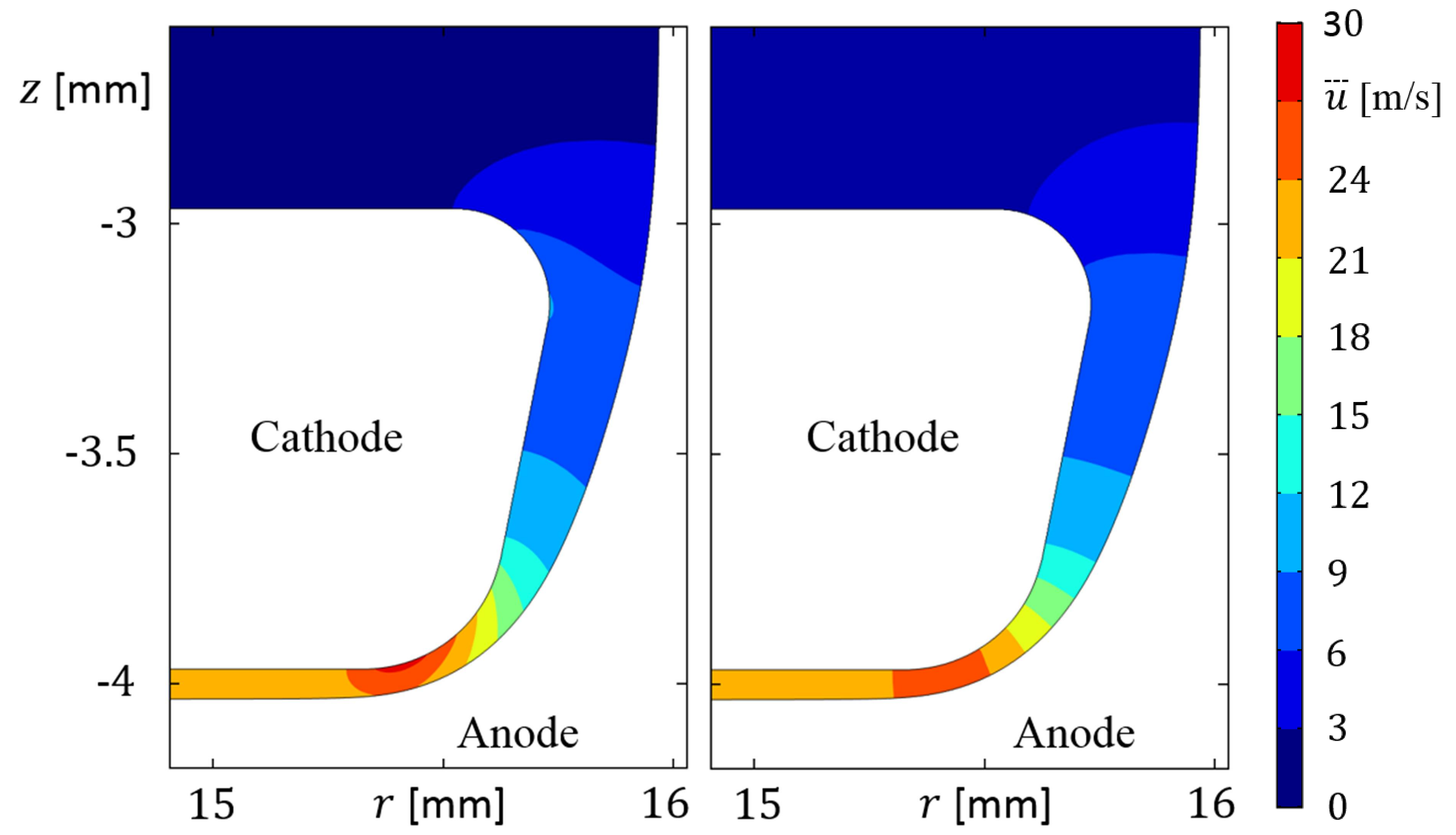

Figure 4. Comparison of the flow velocity magnitude u (left) and the cross-sectional average velocity $\bar{u}$ (right)

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