Understanding antral contraction in human stomach through comparison with soft elastic reactor

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Understanding antral contraction in human stomach using a chemical engineering approach

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Context

Human digestion, a major concern

- **Rapid development of nutrition-related chronic diseases** (eg, obesity, diabetes) affecting a growing population at a global scale
- Gastric digestion relies on **combined effects of enzymatic reactions and mixing and homogenization** of the GI tract content by **antral contraction waves** (ACWs) (Kwiatek et al. 2006, *J. Magn. Reson. Imaging* 24, 1101-1109)
- **Breakdown mechanisms** of food in the GI tract **far from being understood**

Modelling approaches of transport phenomena in the GI tract

- Existing 1D or 2D CFD approaches (Kozu et al. 2010, *Food Biophys*. 5, 330-336; Ferrua et al. 2015, *Curr. Opinion Food Sci*. 4, 116–123) provides fine description of velocity field and eddy structures at a local scale
- **However, needs for a more global understanding of the transport phenomena at the GI tract scale**

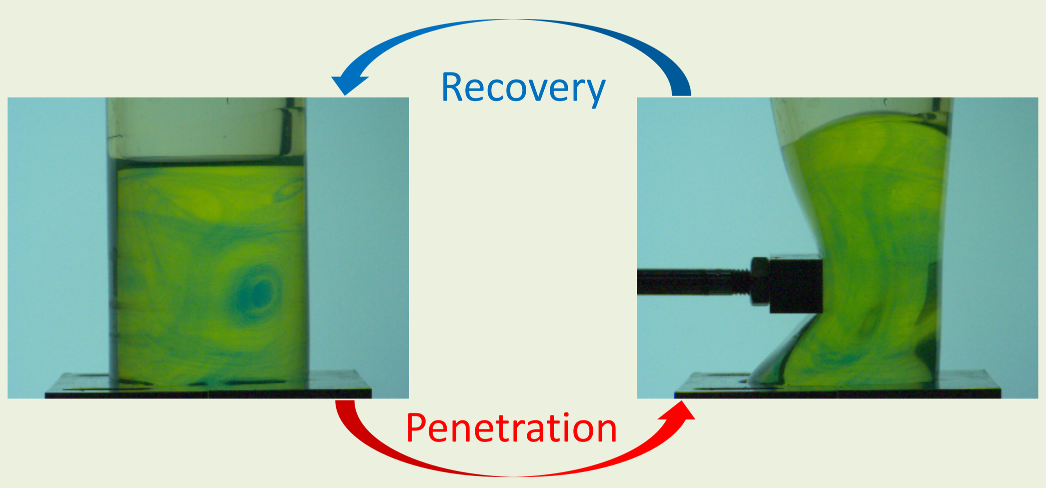
Objectives

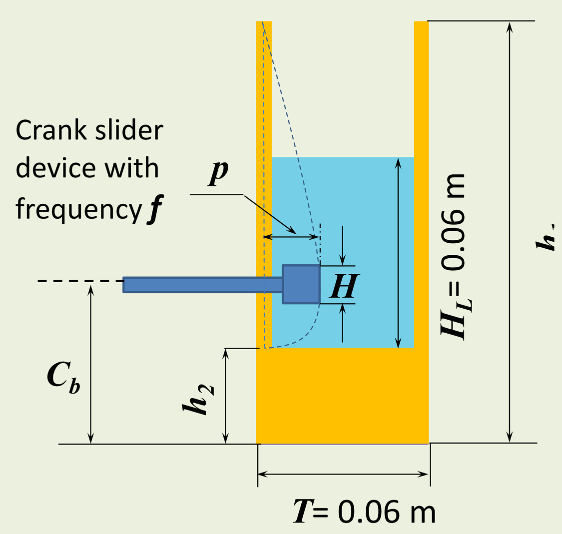
Study the **influence of ACWs amplitude and viscosity of the digesta on the human gastric homogenization process**, based on the knowledge of the **mixing curve of an innovative Soft Elastic Reactor (SER) inducing mixing** by vibration of its wall **in a similar way as ACWs promoting stomach motility**

Soft Elastic Reactor: principle and mixing behaviour assessment

Innovative reactor that promotes mixing through elastic wall movement (Chen and Liu, 2015, Patent number: CN104841299A)

- **tank made of soft elastic silicone** (total height h_1, base height h_2, liquid height H_L, inner diameter T)
- **slider crank device** (penetration depth *p*, frequency *f*, height H, bottom clearance C_b)



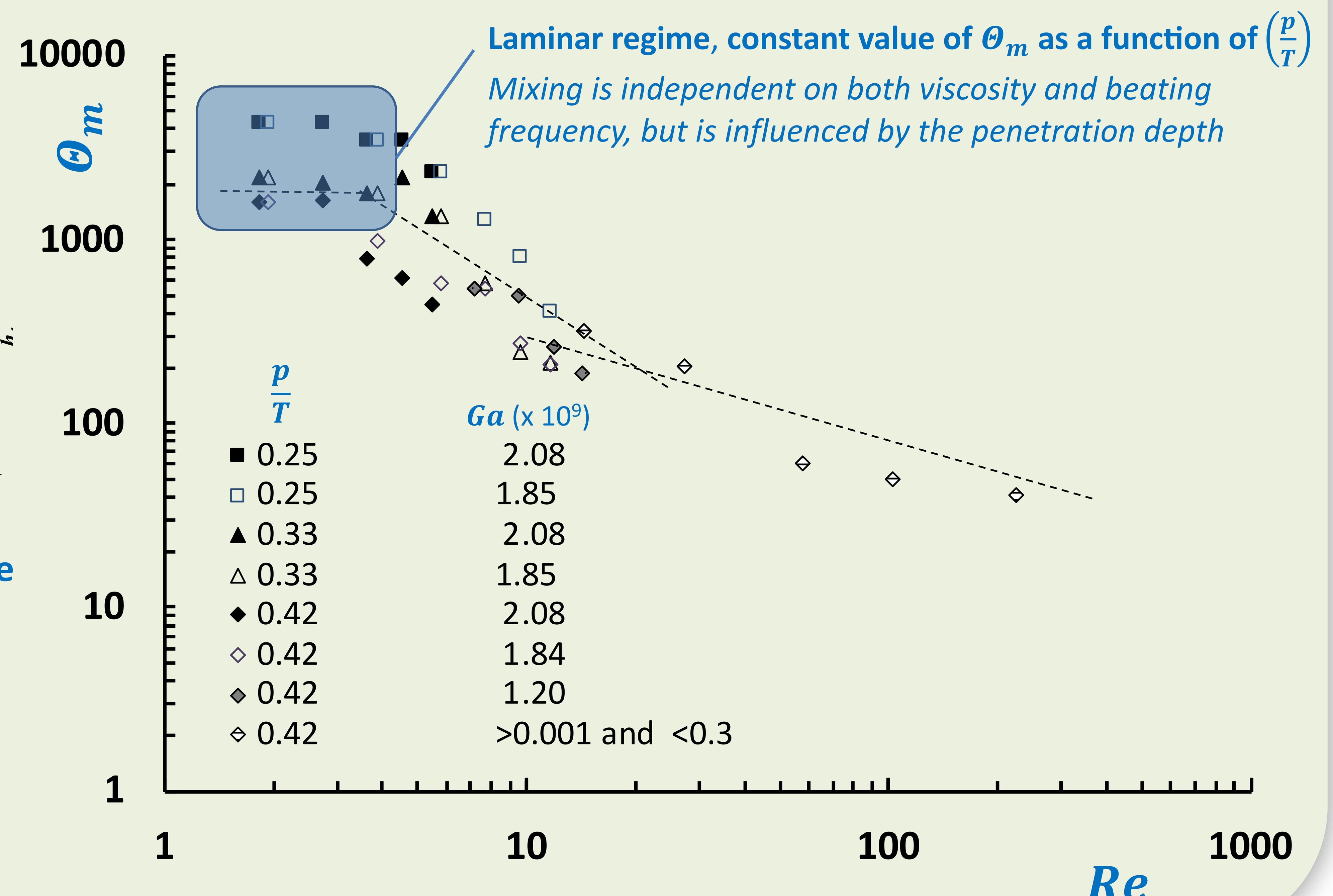


SER performance studied using a dimensional approach of the mixing time (Delaplace et al., 2018, *Chem. Eng. Sci.* 192, 1071-1080)

$$\boldsymbol{\Theta_m = f \cdot t_m = F\left(Re = \frac{\rho \cdot f \cdot T^2}{\mu}, \frac{p}{T}, Ga = \frac{g \cdot T^3 \cdot \rho^2}{\mu^2}\right)}$$

- $\boldsymbol{\Theta_m}$ number of strikes required to achieve the desired degree of homogeneity,
- $\boldsymbol{Re}$ Reynolds number, represents the viscosity $\boldsymbol{\mu}$ influence
- $\boldsymbol{Ga}$ Galilei number, represents the gravity $\boldsymbol{g}$ influence

Mixing curve of dimensionless mixing time number Θ_m for highly viscous Newtonian fluids (μ ranging from 0.0285 Pa·s to 1.187 Pa·s)



Comparison between gastric fluid mixing by stomach peristalsis and SER mixing

Influence of the fluid viscosity on the intragastric mixing performance (Ferrua et al., 2014, *J. Biomech*. 47, 3664–3673)

- CFD approach of gastric digestion and mixing of Newtonian fluids
- The **mixing performance was shown to be independent of the digesta viscosity when μ > 0.17 Pa·s**
- The **number of ACWs experienced by the meal during its residence time in the stomach was shown not to be always sufficient** to achieve homogeneity

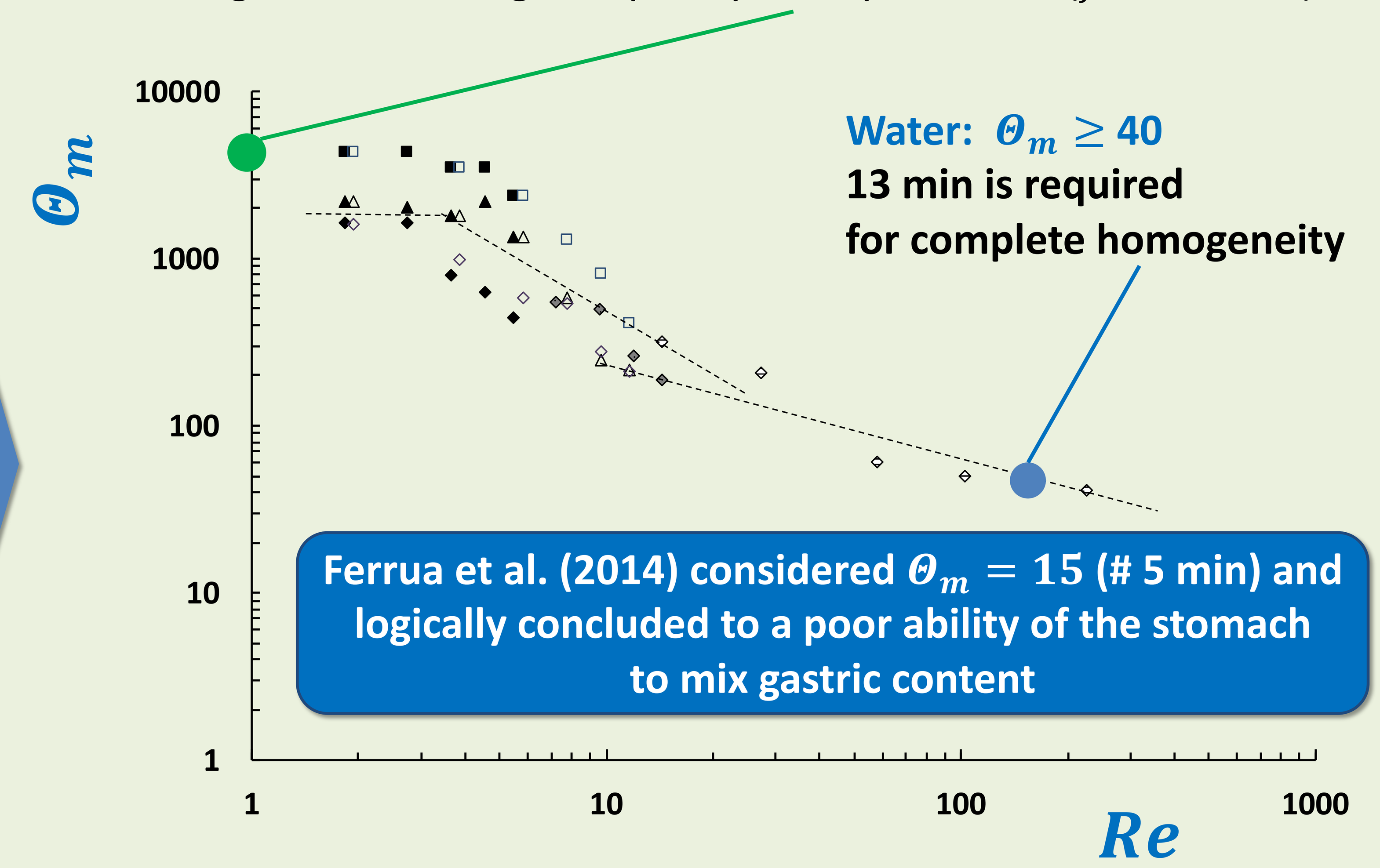
Is the residence time in the human stomach sufficient to ensure homogeneity by wall motility?

Calculation of $\boldsymbol{Re}$ using ($\boldsymbol{\mu}, \boldsymbol{\rho}$) values given in Ferrua et al. (2014), an average antral contraction frequency $\boldsymbol{f} = 0.05$ s[-1] and a characteristic length $\boldsymbol{L_{av}} = 0.052$ m

- **Water** (10^{-3} Pa·s): $\boldsymbol{Re = 150}$
- **Tomato juice** (0.17 Pa·s): $\boldsymbol{Re = 0.91}$
- **Honey** (1 Pa·s): $\boldsymbol{Re = 0.13}$

For ACWs, $\boldsymbol{p}$ = 7.0 ± 0.8 10^{-3} m (Kwiatek et al., 2006) so that $\frac{p}{L_{av}} = 0.13$ > same order of magnitude as the range covered in the SER experiments

Tomato juice and honey: laminar regime and $\boldsymbol{\Theta_m \geq 4600}$
1530 min is required to achieve complete homogeneity
given the average frequency of 3 cycles.min[-1] (f = 0.05 s[-1])



Conclusions

- A **global chemical engineering approach** is proposed to identify the key mechanisms and limiting factors of gastric mixing and digestion
- Based on the mixing curve of the SER, it is confirmed that the level of **mechanical solicitation and the mixing performance of distal region provided by human peristalsis is not as high as expected and confined in laminar regime**
- ACWs mainly ensure a role in transfer of gastric media, and **gastric secretion is thus essential for achieving a good level of homogeneity**

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