UNIVERSITY OF CAMBRIDGE

Paste Particle Polymer Processing

Cleaning by moving liquid jets

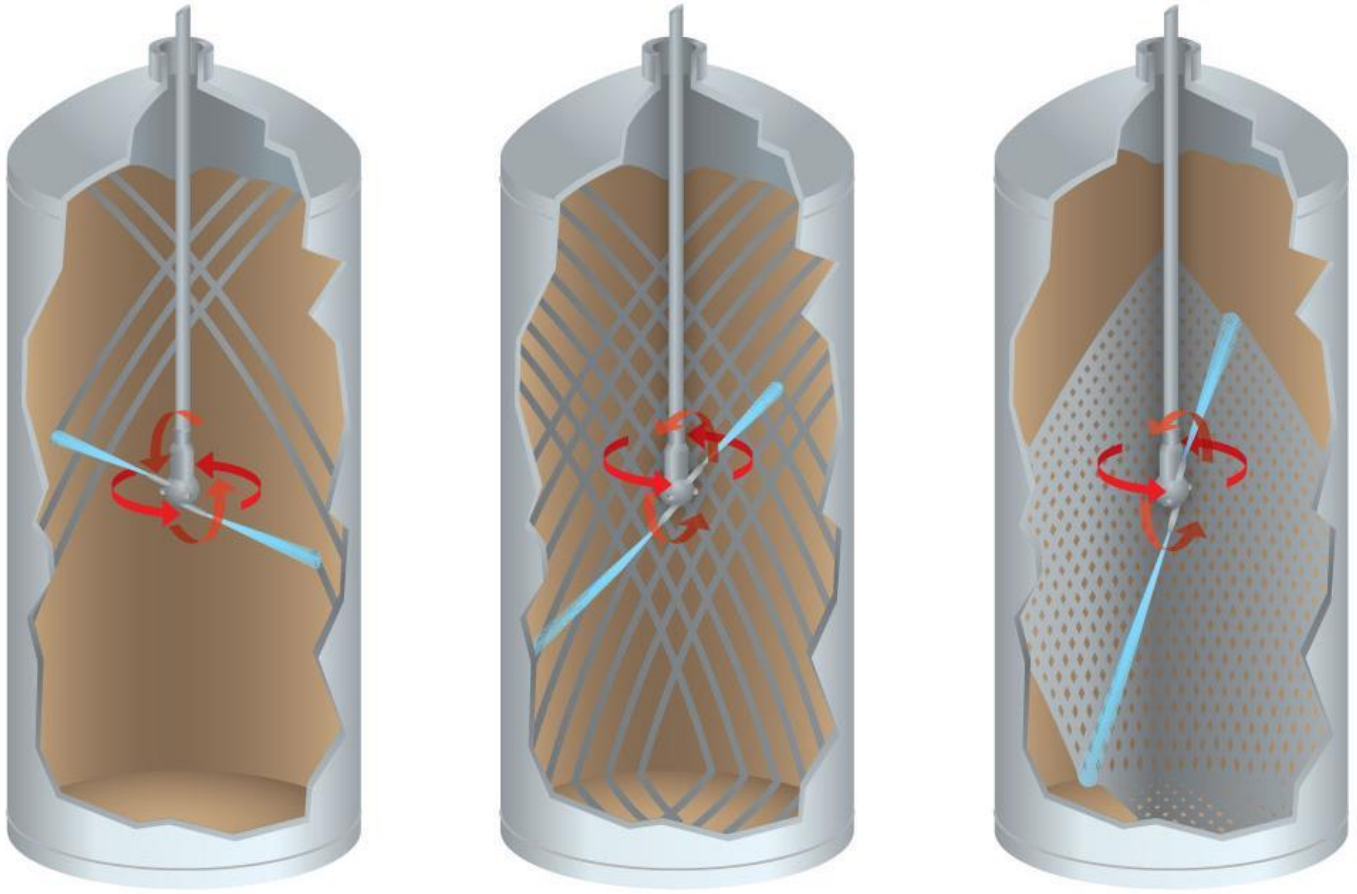
Rajesh Kumar Bhagat

St. John's College

Supervisor: Prof D. Ian Wilson

University of Cambridge

Cleaning in place (CIP); Moving liquid jets



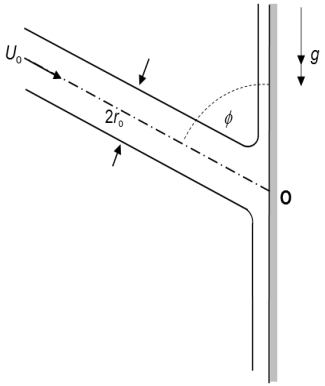
Pictures: Alfa Laval Tank Equipment Inc.

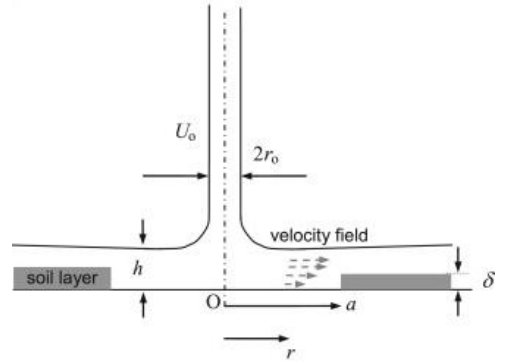
Cleaning by stationary liquid jets

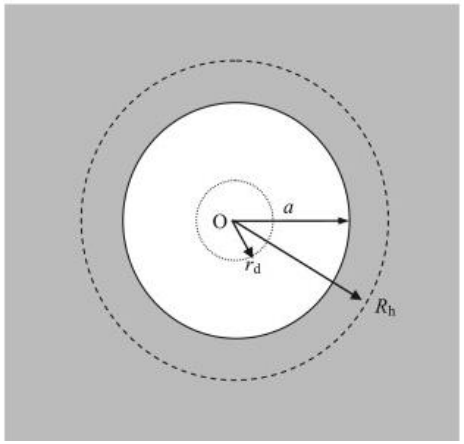
Rate of cleaning is proportional to momentum

$$\frac{\mathrm{d}a}{\mathrm{d}t} = k'M$$

A fraction of momentum is transferred

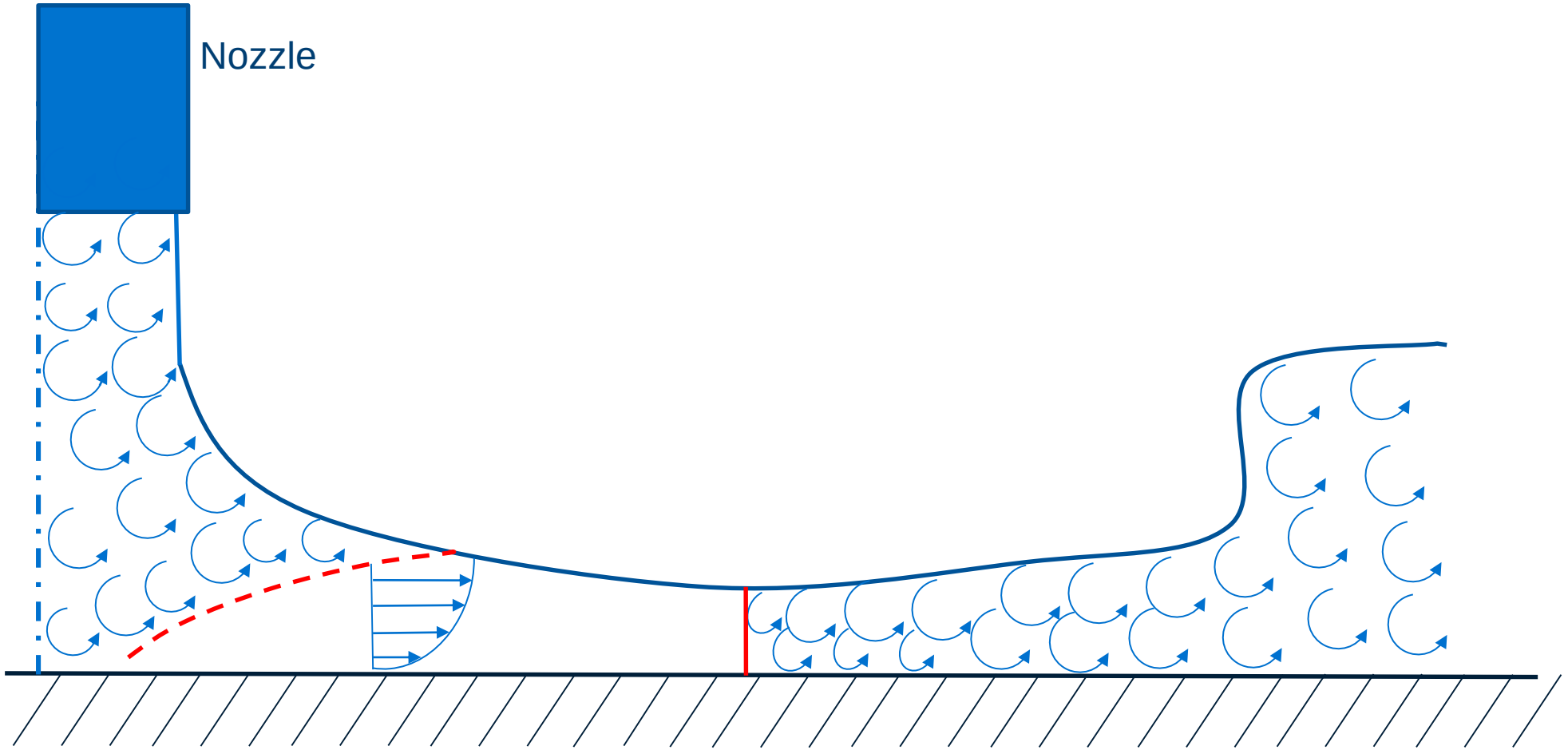






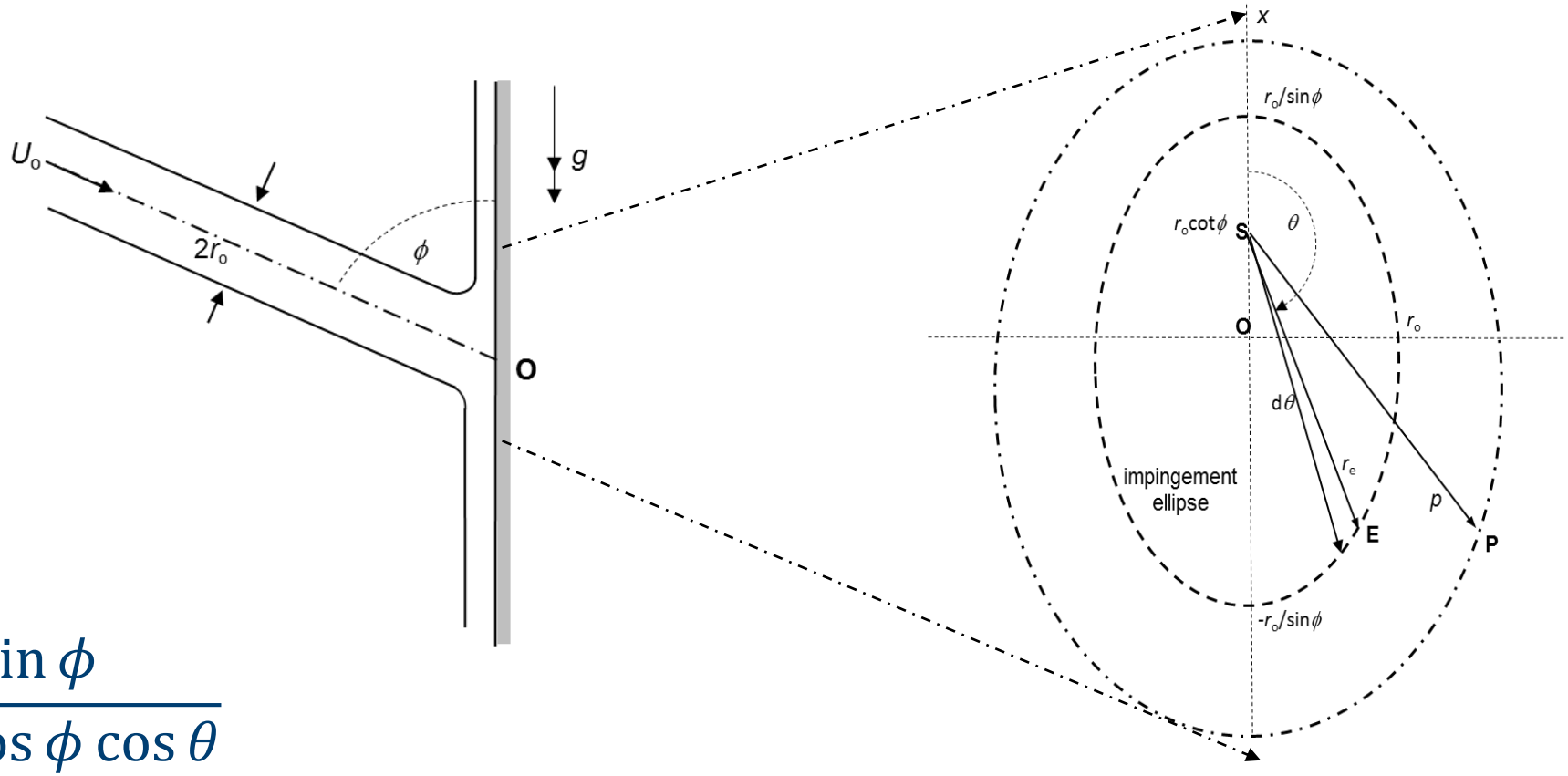
Wilson, D.I., Atkinson, P., Köhler, H., Mauermann, M., Stoye, H., Suddaby, K., Wang, T., Davidson, J.F. and Majschak, J-P. (2014) Cleaning of soft-solid soil layers on vertical and horizontal surfaces by coherent impinging liquid jets, *Chem. Eng. Sci.*, 109, 183–196.

Flow field



Bhagat, R. K., and D. I. Wilson. "Flow in the thin film created by a coherent turbulent water jet impinging on a vertical wall." *Chemical Engineering Science* 152 (2016): 606-623.

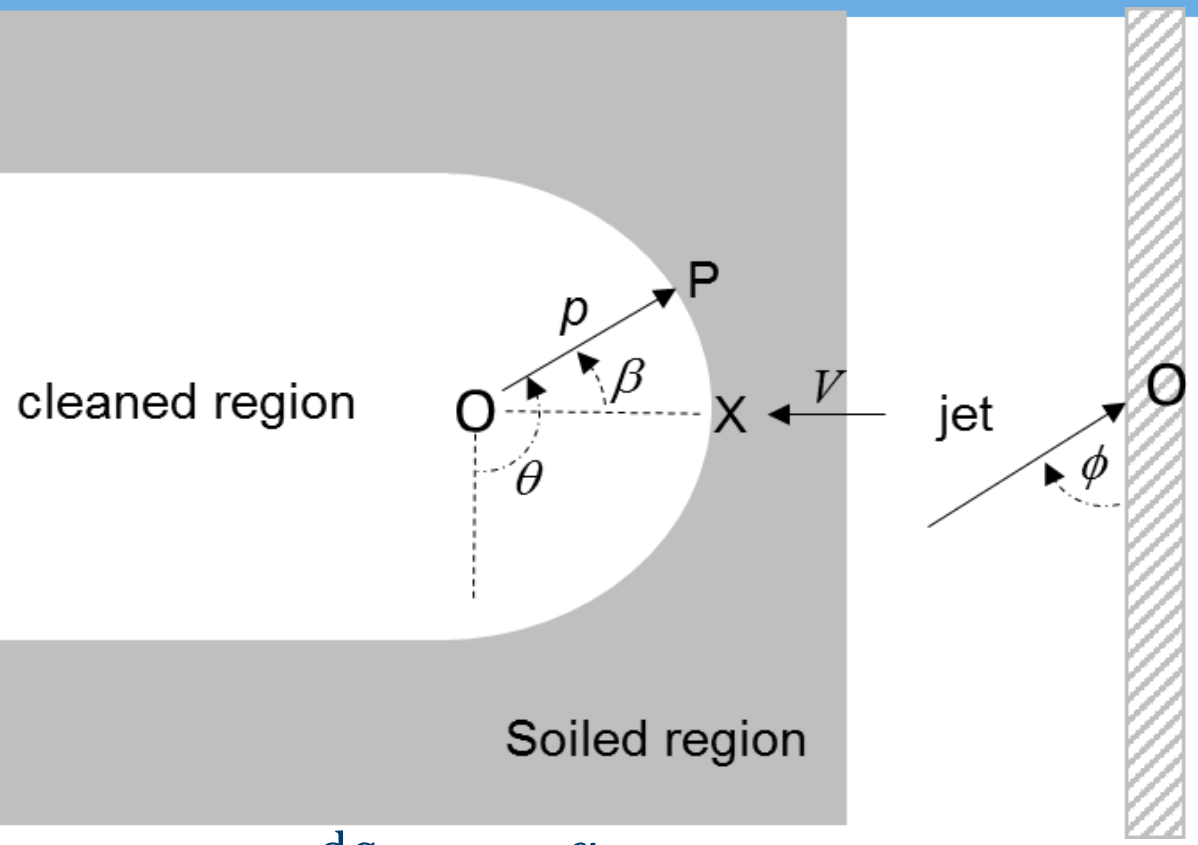
Obliquely impinging jets

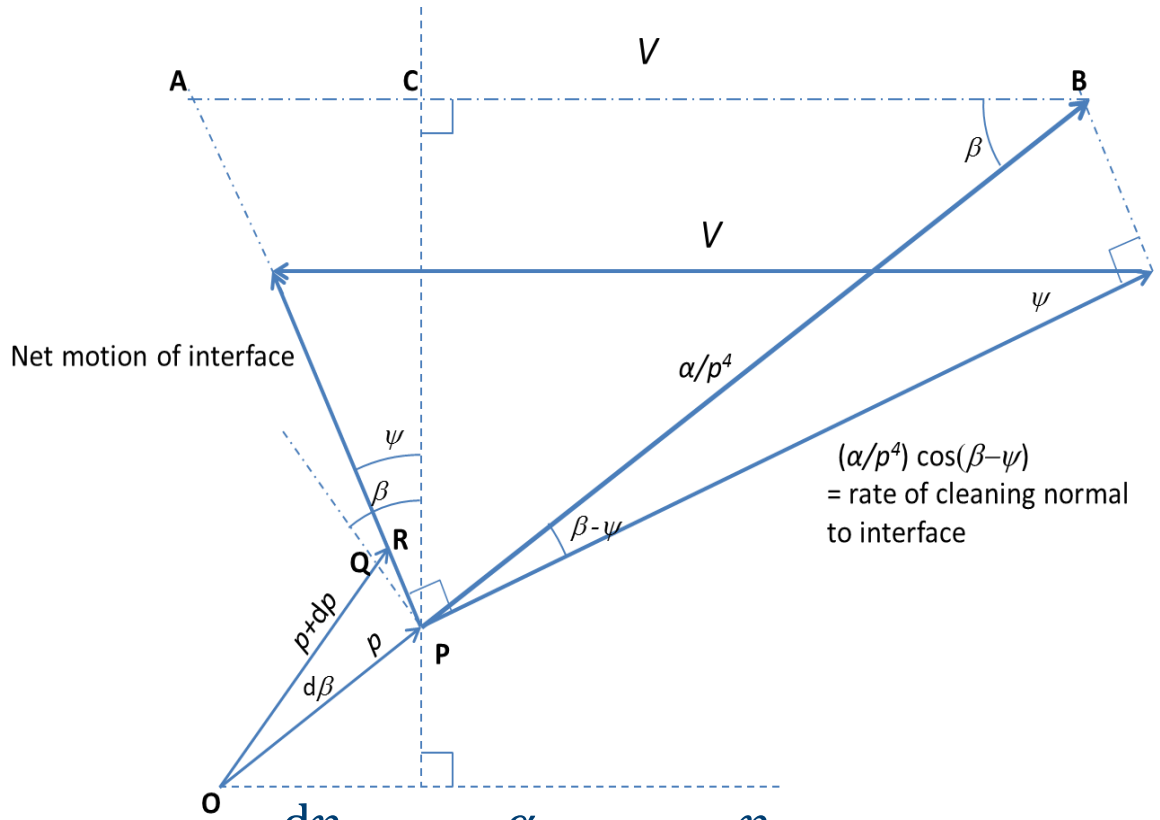


$$\frac{r_e}{r_0} = \frac{\sin\phi}{1 + \cos\phi\cos\theta}$$

Kate, R. P., Das, P. K. and Chakraborty, S. (2007) Hydraulic jumps due to oblique impingement of circular liquid jets on a flat horizontal surface. *J. Fluid Mech.*, 573, 247-263.

Cleaning by moving liquid jets



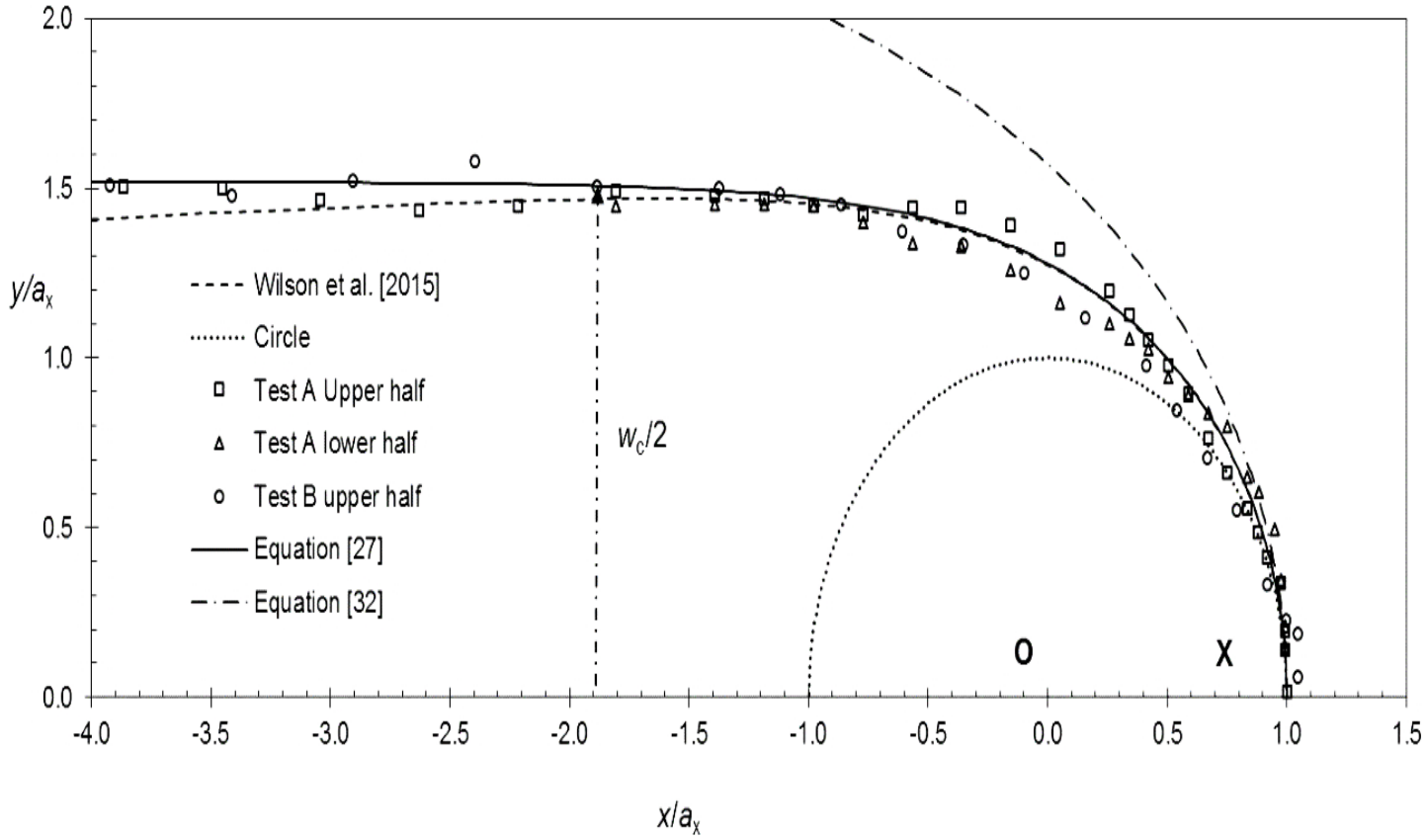


$$\frac{\mathrm{d}a}{\mathrm{d}t} = V = \frac{\alpha}{a_x^4}$$

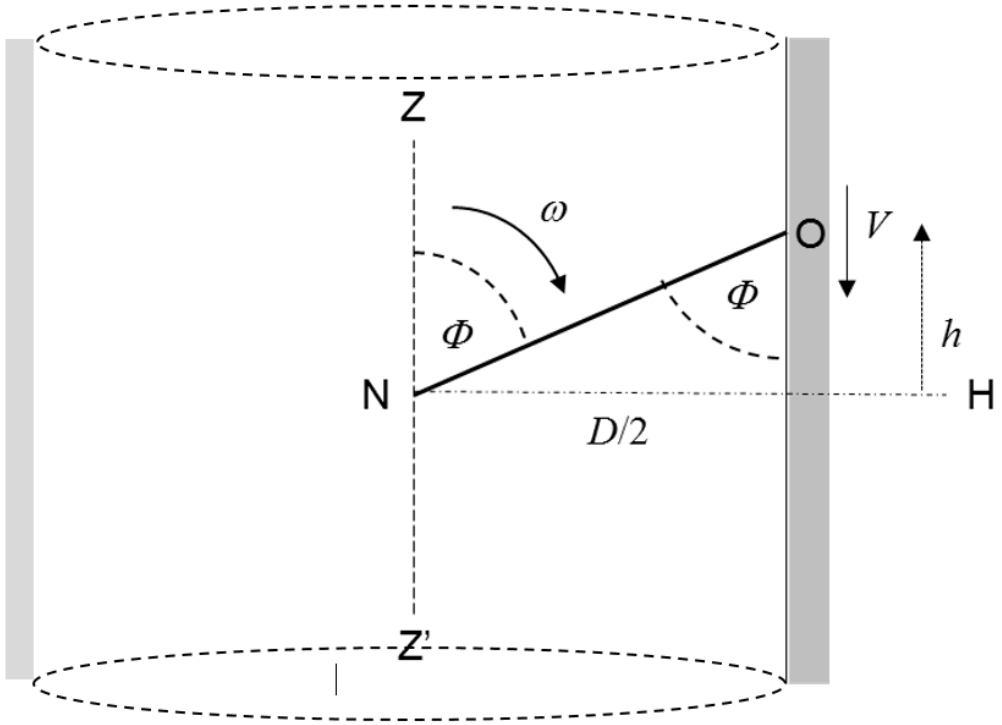
$$\frac{\mathrm{d}p}{\mathrm{d}\beta} = \frac{\alpha}{Vp^3 \sin\beta} - \frac{p}{\tan\beta}$$

Wilson, D.I., Köhler, H., Cai, L., Majschak, J-P. and Davidson, J.F. (2015) Cleaning of a model food soil from horizontal plates by a moving vertical water jet, *Chem. Eng. Sci.* 123, 450-459.

Moving jets: Results



Tank Cleaning by moving jets



Model: Case A: D^+/U^-

$$a_{x,\phi} = \left(\frac{9k'}{50}\right)^{1/4} \left(\frac{\rho}{\nu} r_o^6 U_o^3\right)^{1/4} \left[\frac{\sin^9\phi}{(1+\cos\phi)^6}\right]^{1/4} V^{-1/4}$$

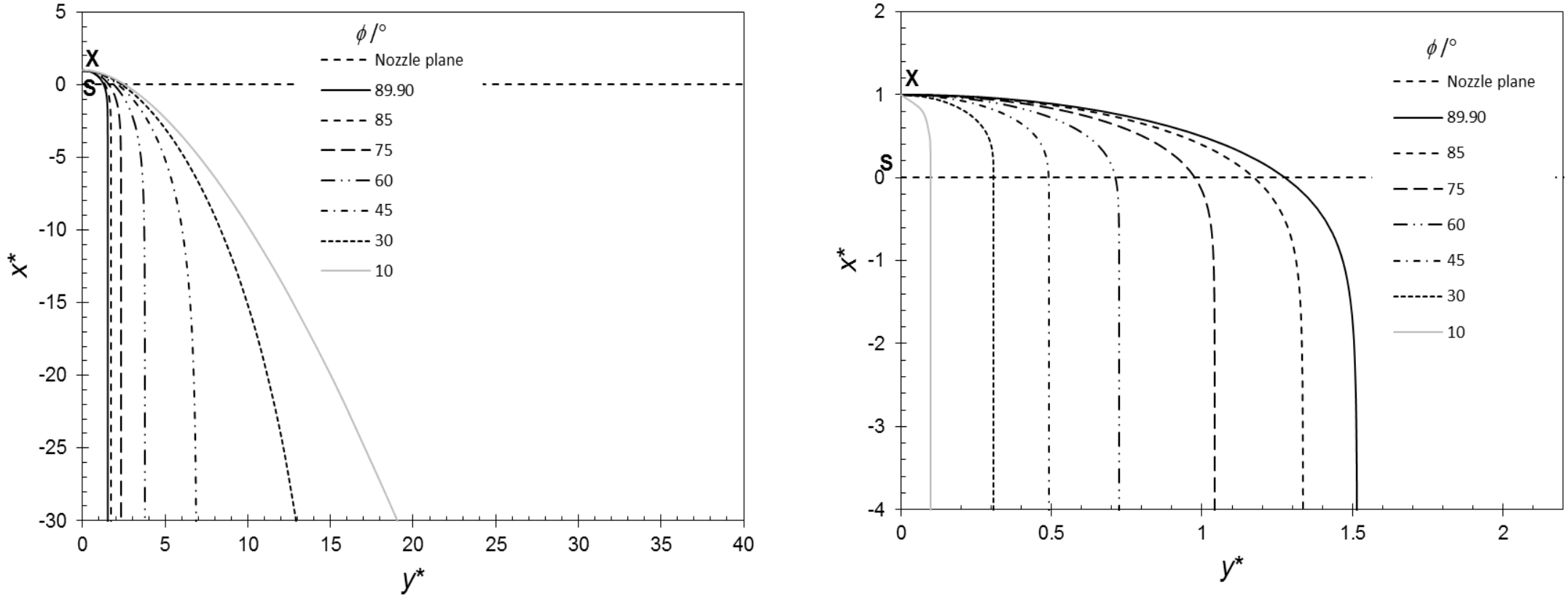
$$p^{*3}\frac{dp^*}{d\theta} + \frac{p^{*4}}{\tan\theta} = \left[\frac{1+\cos\phi}{1+\cos\phi\cos\theta}\right]^6 \sin^3\theta$$

$$w_c = f(U_0, r_0, \phi, V)$$

$$w_c = \left(\frac{32}{15}\right)^{1/4} \left(\frac{9k'}{50}\right)^{1/4} \left(\frac{\rho}{\nu} r_0^6 U_0^3\right) \left[\frac{\sin^9\phi}{(1+\cos\phi)^6}\right]^{1/4} [\sec\phi + 1]^{3/2} \left[\frac{4-\sec\phi}{(\sec\phi-1)^4} + \frac{4-\sec\phi}{(\sec\phi+1)^4}\right] V^{-1/4}$$

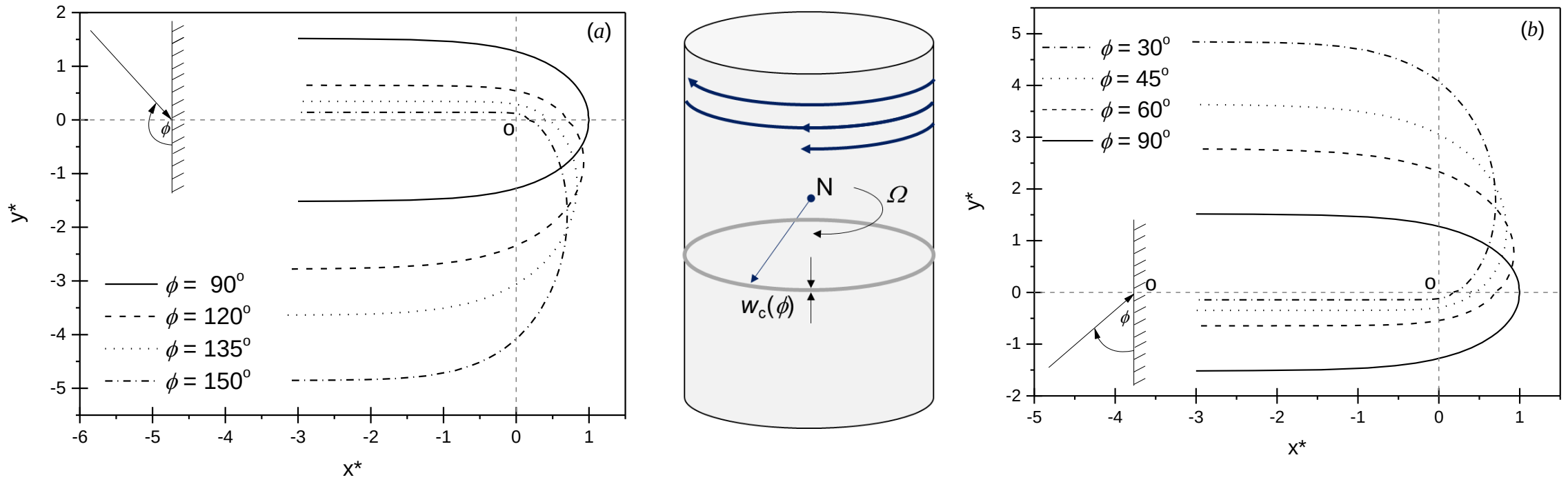
Bhagat, R. K., A. M. Perera, and D. I. Wilson. "Cleaning vessel walls by moving water jets: Simple models and supporting experiments." *Food and Bioproducts Processing* 102 (2017): 31-54.

Tank Cleaning by moving jets: Results



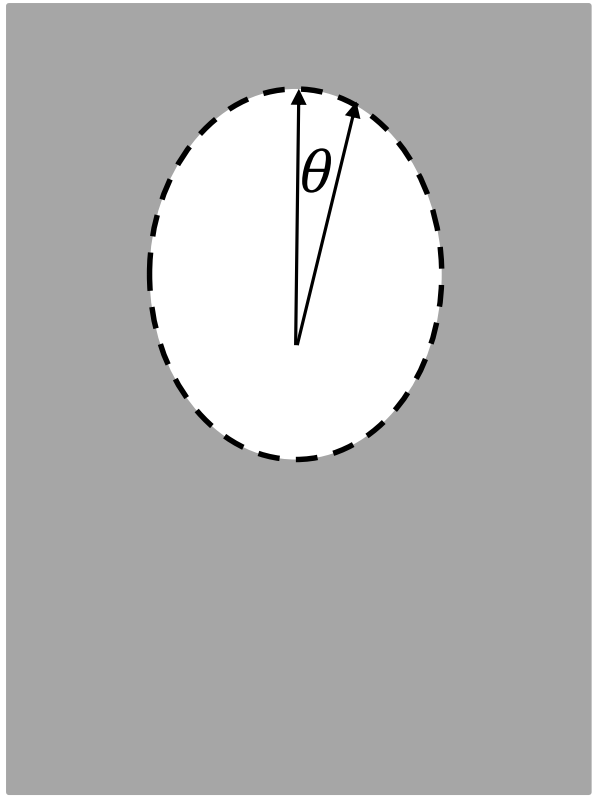
Predicted shapes of cleaning fronts for different angles of impingement, ϕ, for (*a*) Case A, D^+, U^-; (*b*) Case B, D^-, U^+ (see Figure 10). Inset in (*a*) shows trend at large x^*. Dimensionless Cartesian coordinates, $x^* = x/a_{x,\phi}$; $y^* = y/a_{x,\phi}$. X and S are the stagnation point on the cleaning path and the source of the flow, respectively.

Sideways tank cleaning



Effect of angle of inclination on the shape of region cleared by nozzle moving normal to liquid jet direction for (b) $\phi \leq 90°$ and (a) $\phi \geq 90°$. O is the point of impingement.

Cleaning by obliquely impinging jet: Results……..

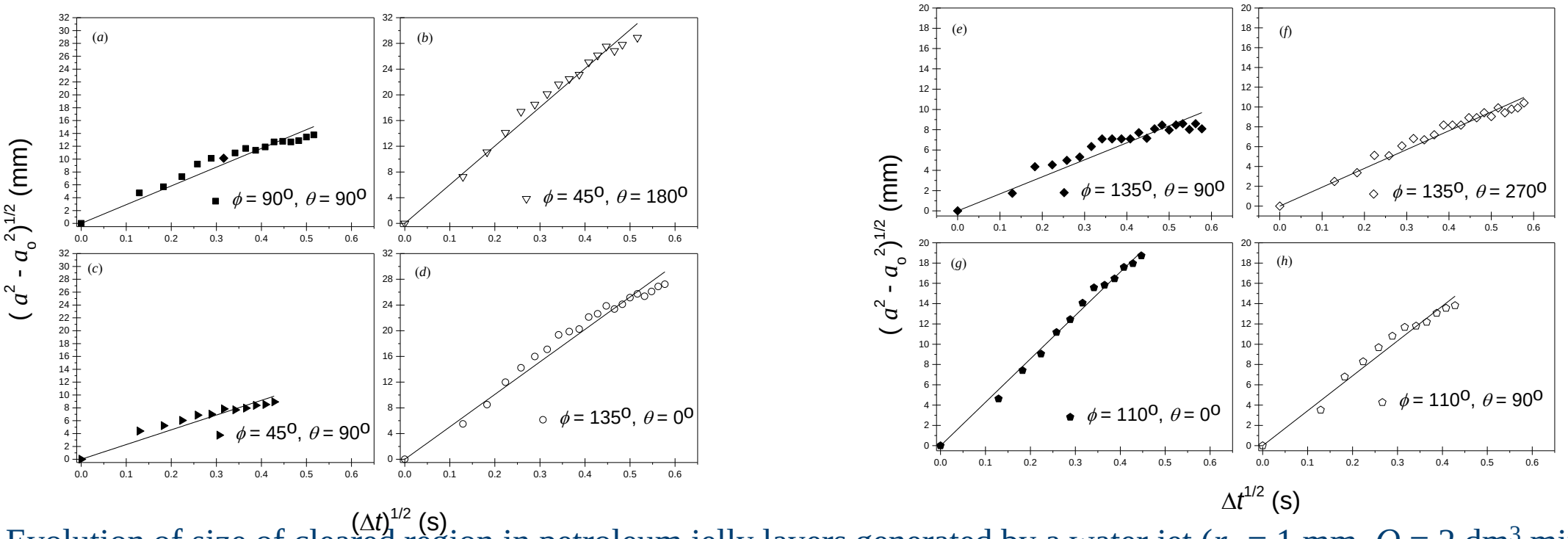


$$\frac{\mathrm{d}a}{\mathrm{d}t} = \left[\frac{9k'}{50}\rho r_e^2 U_0^2 \sin\phi\right]\frac{1}{a}$$

$$\Delta a^2 = 2\sigma_{\theta,\phi}\Delta t$$

$$\sigma_{\theta\phi} = \mathrm{f}(Q, r_o, \theta, \phi)$$

Cleaning by obliquely impinging jet: Results



Evolution of size of cleared region in petroleum jelly layers generated by a water jet (r_o = 1 mm, Q = 2 dm^3 min^{-1}, Re_{jet} = 21,800) impinging at angles indicated

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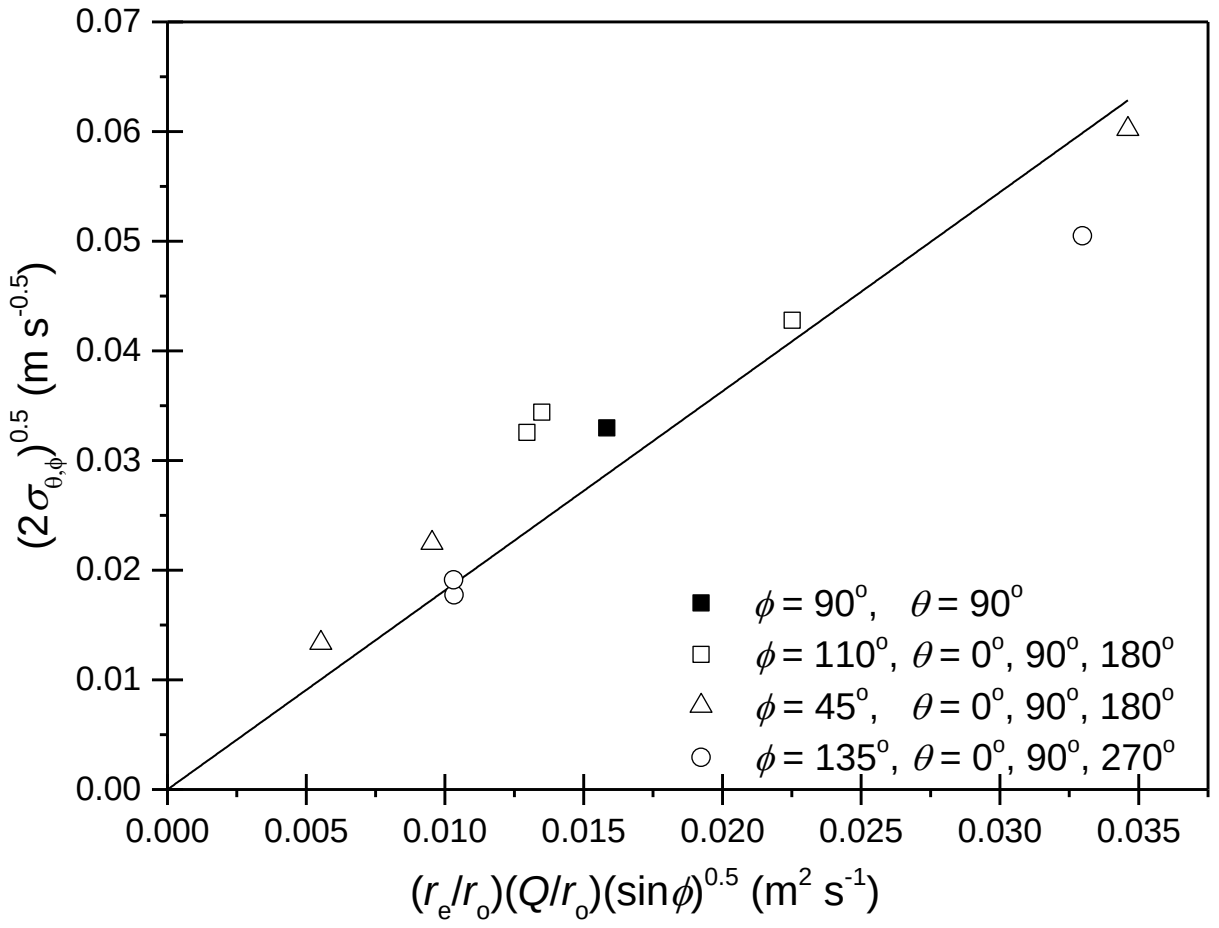
Cleaning by obliquely impinging jet: Results……..



$$\frac{\mathrm{d}a}{\mathrm{d}t} = \left[\frac{9k'}{50}\rho r_e^2 U_0^2 \sin\phi\right]\frac{1}{a}$$

$$\Delta a^2 = 2\sigma_{\theta,\phi}\Delta t$$

$$\sigma_{\theta\phi} = \mathrm{f}(Q, r_o, \theta, \phi)$$

Summary

- Cleaning by obliquely impinging jets
- Model for cleaning by moving liquid jets
- Cleaning performance can be evaluated based on these model

Thank you

References

- Wilson, D. I., et al. "Cleaning of a model food soil from horizontal plates by a moving vertical water jet." *Chemical Engineering Science* 123 (2015): 450-459.
- Bhagat, R. K., and D. I. Wilson. "Flow in the thin film created by a coherent turbulent water jet impinging on a vertical wall." *Chemical Engineering Science* 152 (2016): 606-623.
- Bhagat, R. K., A. M. Perera, and D. I. Wilson. "Cleaning vessel walls by moving water jets: Simple models and supporting experiments." *Food and Bioproducts Processing* 102 (2017): 31-54.
- Glover, H. W., et al. "Cleaning of complex soil layers on vertical walls by fixed and moving impinging liquid jets." *Journal of Food Engineering* 178 (2016): 95-109.
- Kate, R. P., P. K. Das, and Suman Chakraborty. "Hydraulic jumps due to oblique impingement of circular liquid jets on a flat horizontal surface." *Journal of Fluid Mechanics* 573 (2007): 247-263.