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Superhydrophobic Surfaces in Water and Wastewater and Effect on Velocity and Flow Structure

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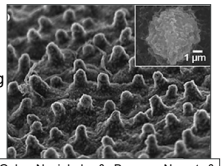
INTRODUCTION

Superhydrophobic surfaces mimic natural surfaces such as fish scales and lotus leaves with its ability to repel water droplets.

For a surface to be classified as "superhydrophobic" it must meet criteria including a high apparent contact angle (>150°), a low contact angle hysteresis (<10°), a low sliding angle (<5°) and high stability of the Cassie-Baxter model, which specifies stability of a high contact angle due to a surface composed of both solid and air, preventing water penetration and complete surface contact. To achieve this, a superhydrophobic surface is composed of nano and micro scale morphology, creating air pockets that cause repellence between the water and the surface.

This research aims to explore current literature relating to superhydrophobic surfaces and the potential applications in a water and wastewater, especially in a pipe application capacity. It is hypothesised that these surfaces would reduce friction factor and the amount of time between maintenance and cleaning activities due to the inherent anti-fouling nature of superhydrophobic coatings. These coatings are also known to inhibit bacterial growth on the same level as some chemical reagents.



Gule, Nonjabulo & Begum, Nusrat & Klumperman, Bert. (2015). Advances in Biofouling Mitigation- A review.

METHODS

General Approach

- Review of existing superhydrophobic literature and research.
- Applying natural superhydrophobic surfaces to real world uses.
- Scoring proposed solutions based on cost, practicality and likelihood of success.
- Reviewing experimentation limited to a lab context and making it practicable.

Solution Costings

- 4 common pipe sizes and 3 common materials were selected and the surface areas calculated.
- Materials for each coating layer were costed (micro, nano and protective layers).
- The Dry Film and Wet Film Thicknesses (DFT)(WFT) were used to calculate the spreading rate and how much coating would be required per m^2.

Selection Matrix Set-up

- This matrix and criteria were used to identify the best potential solution

Criteria	Cost	H&S	Material sources	Installation	Durability	UV
Solution 1						
Solution 2						
Solution 3						

Rating	
1	- Not suitable for industrial applications
2	- May be fit for purpose, with adjustments
3	- Meets industrial application needs
4	- Exceeds industrial application needs

RESULTS

Proposed Solution Selection Matrix Results

Criteria	Cost	H&S	Material sources	Installation	Durability	UV
Solution 1	4	2	3	3	4	4
Solution 2	3	2	3	3	3	4
Solution 3	2	1	3	2	4	3

Proposed Solution Costing Results

Solution 1 Total Cost Per Pipe size					
Pipe size	**Pipe material**	**OD (mm)**	**ID(mm)**	**Surface area (m2)**	**Cost ($)/m**
50 mm	PE	50	40	0.1	$11.77
100 mm	PVC	114	100	0.3	$29.44
150 mm	PVC	160	150	0.5	$44.15
250 mm	AC	286	250	0.8	$73.59

Solution 2 Total Cost Per Pipe Size					
Pipe size	**Pipe material**	**OD (mm)**	**ID(mm)**	**Surface area (m2)**	**Cost ($)/m**
50 mm	PE	50	40	0.1	$13.11
100 mm	PVC	114	100	0.3	$32.77
150 mm	PVC	160	150	0.5	$49.15
250 mm	AC	286	250	0.8	$81.91

Solution 3 Total Cost Per Pipe Size					
Pipe size	**Pipe material**	**OD (mm)**	**ID(mm)**	**Surface area (m2)**	**Cost ($)/m**
50 mm	PE	50	40	0.1	$73.77
100 mm	PVC	114	100	0.3	$184.43
150 mm	PVC	160	150	0.5	$276.65
250 mm	AC	286	250	0.8	$461.08

DISCUSSION

Review of Existing Experimental Research

Lab experiments don't replicate a real industrial system → Products used are not food safe or fit for purpose (i.e. no surface morphology) → Lack of durability is a common theme amongst all superhydrophobic coatings → Proposed Solutions

Reynolds Number Limitations

[1][2] Both of these sources present Reynolds number limitations in both pressurized systems and non-pressurized systems. They illustrate that there is significant % drag and friction factor reduction for smaller Reynolds numbers (Figure 1 & 2), but this effect reduces the higher the Reynolds number. This effect should be approached with skepticism as these coatings applied were not fit for purpose.

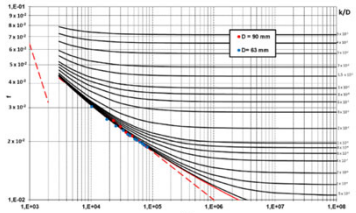


Figure 1 – Moody charts depicting the experimental friction factors values for the untreated PVC pipes [1].

Slip Rate Condition

[2] Mentions that the reduction % drag reduction reduces with Reynolds number. This could be due to a partial slip condition. The degree of slip reduction decreases with surface roughness and is dependent on the sheer rate near the surface. This condition is not necessarily negative:

- It can cause flow complexities especially with modelling.
- There is a reduction in flow resistance, which is desirable to maximize flow.
- It can fundamentally change the calculated properties like permeability of porous media.

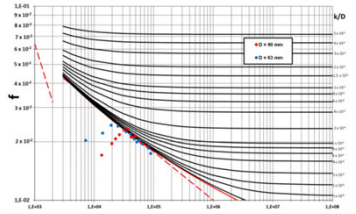


Figure 2 – Moody charts depicting the experimental friction factors values for the treated PVC pipes [1].

Potential Solution Matrix and Costing Results

- As the materials selected for these potential solutions are food safe, they have a higher cost.
- Bulk supply of smart textiles are not widely available.
- Most of the constituents of the proposed coatings are priced with lab grade chemicals due to limited availability of bulk supply.
- Solution 1 scored the highest and based the proposed criteria. This demonstrates that there is potential for industrial implementation, but material costing is the restricting factor.
- The proposed solution coating constituents are highlighted in the adjacent figure.

CONCLUSIONS

Final Thoughts

- The coatings are affordable and costs can be brought down further with proper sourcing.
- There are other potential applications within the water and wastewater industry:
  - Intake screens to avoid blockage and buildup of algae.
  - Membranes to avoid build-up and less maintenance requirements.
  - Centrifuges and sludge transport mechanisms for antimicrobial and anti-stick properties to avoid blockages and sludge conveyors.
  - Tanks to avoid microbial build up.

Future Work

1. R&D with a variety of materials that could be fit for purpose.
2. Testing in a variety of flow situations to identify and mitigate partial slip properties with hierarchical structure.
3. Durability and performance testing in a variety of realistic applications.
4. Exploration of potential leachates from proposed coating.

References: [1] Antonio J. Munoz, J. R. (2024). Application of a hydrophobic coating to a pressurized pipe and its effect on energy losses and fluid flow profile; [2] .H. Chen, C. T. (2010). An Experimental Study of Drag Reduction in a Pipe with Superhydrophobic Coating at Moderate Reynolds Numbers . EDP Sciences; [3] Dulux. (n.d.). Handy Calculations - Volume Solids and Spreading Rate. Retrieved from https://www.duluxprotectivecoatings.com.au/media/1581/531_handy_calculations-vol_solids_spread-rate.pdf; [4] Yuxing Bai, H. Z. (2021). Recent Progresses of Superhydrophobic Coatings in Different Application Fields: An Overview. MPI.

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