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Effect of Pore Size and Hydrophobic Coating on Oil-Water Separation System for Grease Trap

Mohamed Saiful Firdaus Hussin[1,*], Azrul Abidin Zakaria[2], Ridhwan Jumaidin[1], Iszmir Nazmi Ismail[2], Mastura Mohammad Taha[1], Muhd Ridzuan Mansor[3], Mohd Fariduddin Mukhtar[1], Amir Abdullah Muhamad Damanhuri[1]

[1] Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Department of Mechanical Engineering, Universiti Tenaga Nasional, Jalan Ikram-Uniten, 43000 Kajang, Selangor, Malaysia
[3] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

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ABSTRACT

Public concern towards solidification of fat, oil, and grease (FOG) through disposed wastes into the drainage system is an unresolved issue to this day. The use of skimmer to separate oil and water form their mixture is a less comprehensive solution. This paper aimed to design the concept and fabricate oil-water separation medium, as well as to analyse the effect of different pore sizes of wire mesh and coating respectively. Water separation system is designed based on Pugh Method, while stainless steel wire mesh is used in analysing the water repellent and oil absorption characteristics. Titanium dioxide is used as coating. Surface characterization and contact angle of droplet were observed using scanning electron microscope and contact angle measurement tools. Hydrophobicity of uncoated stainless steel of wire mesh will increase if the pore size of wire mesh is decreasing in size. The more layers of coating increase the hydrophobicity of the wire mesh in increments with contact angle more than 100°. For the cooking oil droplet to expeditiously spread over the mesh surface and rapidly permeate through the mesh less than 1 second, showed the oleophilic nature of the mesh.

1. Introduction

Fat, oil, and grease (FOG) comes from food products such as dairy products, butter, vegetable oil, animal fat, meat, and sauces. Restaurants, cafes, and other food service providers are the main contributor where foods are prepared, cooked, and served. Improper handling of food wastes will lead to blocked sewer and unpleasant smells. Absorbent materials have pores absorbent properties to absorb oil from water by opposite wetting behavior [1]. Despite, the process of oil spillage clearance is still difficult. A number of studies were carried out regarding the separation of oil and water using metal wire mesh as filter that only allows oil flow through the pores and repel water [2-4]. Metal meshes are capable of separating large quantities of mixed oil-water. They possessed better

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[*] *Corresponding author.*
E-mail address: mohamed.saiful@utem.edu.my

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mechanical behavior, cost-effective fabrication procedures [5] and only low pressure is required to drive liquid through metal meshes because gravity alone can be used to drive the flow [6]. Copper is commonly used for fabricating superhydrophobic materials. It is used in oil water separation because it has great extensibility, adjustable pore sizes, and good thermal conductivity [7]. Pore size of mesh plays an important factor by shrinking the pore size the intrusion pressure for water will increase but at the same time, the oil flux through the mesh is reduced. The delicate balance between the intrusion pressure and oil flux can determine the optimal size of the superhydrophobic meshes [8]. This research aimed to design and fabricate a new oil-water separation medium, as well as investigate the mesh filter performance and efficiency in separating oil and water for grease trap [9]. It is expected that most efficient pore size and coating will be the outcome of the experiment.

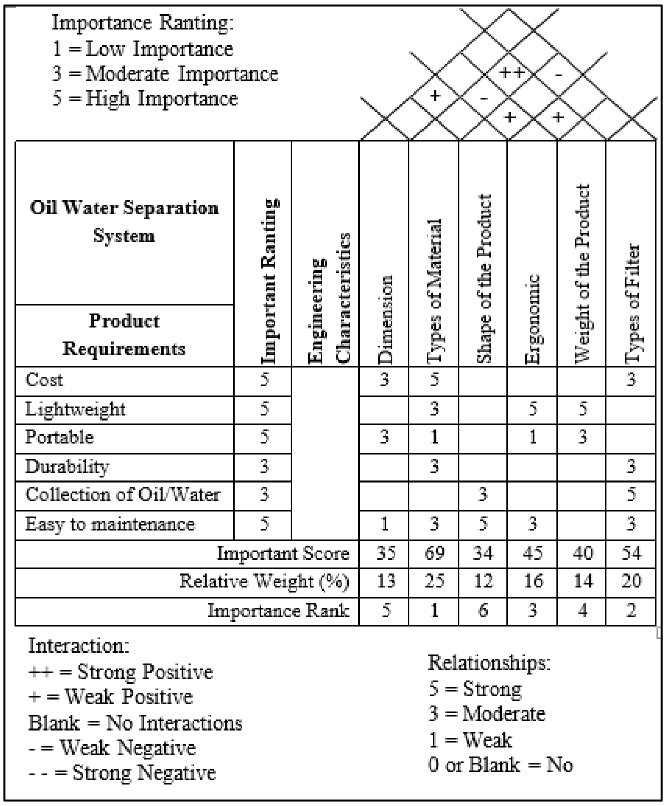
2. Methodology

House of quality is applied to convert customer requirement into proper plan, prioritizing steps from many options which the most important to customer and do the realistic plan in connecting engineering element and product requirement [10]. Morphological chart is then used to generate ideas and concepts by visual selection [11,12]. Later, Pugh method is used to evaluate and decide the best concepts generated by morphological chart [13]. The material selection of this project is based on the wettability properties. Material characterization is done by analyzing the water contact angle and scanning electron microscope.

3. Results

Figure 1 shows the quality house and all the calculations in a single matrix. Within the scope, there are six customer’s requirements considered in designing the oil-water separation system. All of the requirement have quantifiable value that related to the product’s engineering characteristics. Material selection, types of filter, and ergonomic factor are the most regarded issues for supplying present demand at this point. In general, dominance of positive relationships according to roof of the house of quality is an indication of accuracy of company requirements identification. From the morphological chart (Table 1), 4 concepts were developed

i. acrylic > wire mesh filter > straight shape > medium size system > small size water container > medium size oil container > slot assembly
ii. glass > sand filter > cylinder shape > small size system > small size water container > big size oil container > layer assembly
iii. plastic > sponge filter > half round shape > big size system > big size water container > small size oil container > clip assembly
iv. aluminium > aerogel filter > v shape > big size system > medium size water container > small size oil container > screw assembly



Importance Ranting:
1 = Low Importance
3 = Moderate Importance
5 = High Importance

Oil Water Separation System / Product Requirements	Important Ranting	Engineering Characteristics	Dimension	Types of Material	Shape of the Product	Ergonomic	Weight of the Product	Types of Filter
Cost	5		3	5				3
Lightweight	5			3		5	5	
Portable	5		3	1		1	3	
Durability	3			3				3
Collection of Oil/Water	3				3			5
Easy to maintenance	5		1	3	5	3		3
Important Score			35	69	34	45	40	54
Relative Weight (%)			13	25	12	16	14	20
Importance Rank			5	1	6	3	4	2

Interaction:
++ = Strong Positive
+ = Weak Positive
Blank = No Interactions
- = Weak Negative
- - = Strong Negative

Relationships:
5 = Strong
3 = Moderate
1 = Weak
0 or Blank = No

Fig. 1. House of Quality for Filter Design

Table 1
Morphological Chart for Filter Design

Characteristics	Option 1	Option 2	Option 3	Option 4
Body Material	Acrylic	Glass	Plastic	Aluminum
Type of Filter	Aerogel	Wire mesh	Sand/Rock	Sponge
Shape of Filter	Cylinder	Half round	V-shape	Straight
Size of the System	Small	Medium	Medium	Big
Size Container Water	Small	Medium	Medium	Big
Size Container Oil	Small	Medium	Medium	Big
Assemble Parts	Clip	Screw	Layer	Slot

Table 2 shows that the concept 1 of oil water separation is better compared with the datum or reference concept. Concept 1 is selected as the design for further development as it is more than 0.7 with the datum at its highest final score weightage. Meanwhile, both concept 2 and concept 4 have less score compared to the datum. The seven possible combinations of sub-problem solutions can be qualitatively evaluated using a Pugh concept selection method in every single alternative to a datum alternative.

Table 2
Pugh Method for Filter Design

Criterion	Weightage	Concept 1	Concept 2	Concept 3	Concept 4
Body Material	0.1	-1	0	DATUM	-1
Type of Filter	0.2	1	-1		0
Shape of Filter	0.1	0	-1		1
Size of the System	0.2	1	0		0
Size Container Water	0.1	0	0		0
Size Container Oil	0.2	1	1		0
Assemble Parts	0.2	1	-1		-1
Total (+ve) 1		4	1	-	1
Total (-ve) -1		1	3	-	2
Final score		3	-2	-	-1
Final score weightage		0.7	-0.3	-	-0.2

The surface morphology variation of stainless steel wire mesh before (Figure 2) and after coating 14 times of layer TiO_2 (Figure 3) were presented by *SEM. SEM* was used to investigate the surface morphology of the wire mesh. The original wire mesh has a clean and smooth surface as shown in Figure 2. After process coating 14 times layer of TiO_2 on the surface of the wire mesh, it can be seen that the hole channels of mesh are covered with TiO_2 film on it. It is obvious that relative roughness could be observed compared with original one. Thus, this TiO_2 material is able to change the surface of this stainless steel wire mesh in rough conditions. The surface wettability of pure metals can be changed by surface modification and increasing the roughness [14]. The rough structure contributes the formation of air pockets, which can capture a large amount of air; air pockets trap the air between the wire mesh and the water droplet resulting in a composite interface. Cassie-Baxter model has classically been used to describe the phenomena [15]. In other word, the increase of water-air contact area means the increase of contact angle value. Therefore, the morphology of the prepared surface provides the geometric condition for the hydrophobic and low adhesive properties. Furthermore, the mesh maintains high water resistance due to the high surface roughness and low surface energy, preventing the water molecules from contacting the mesh [16].

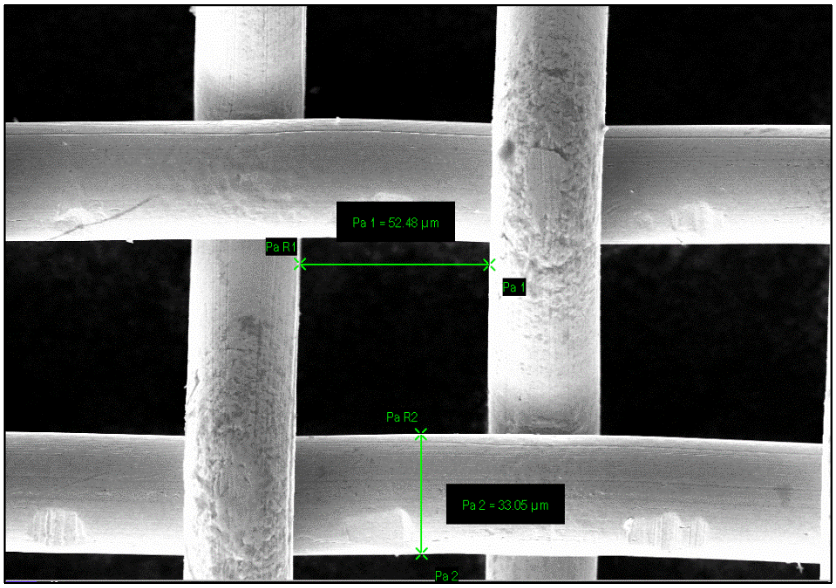


Fig. 2. SEM image of uncoated stainless steel wire mesh at magnifications of 500 X

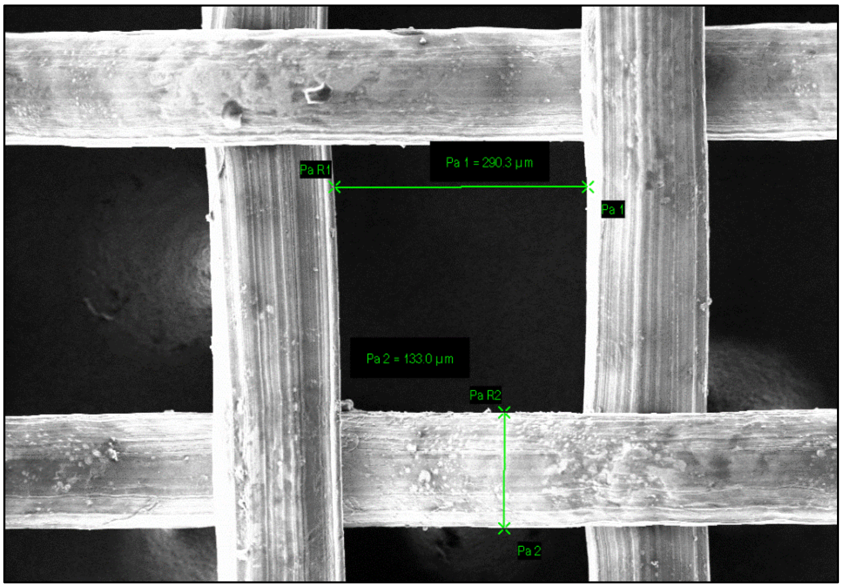


Fig. 3. SEM image of stainless steel wire mesh coated with TiO$_2$ 14 times at magnifications of 500 X.

Generally, the results show that as the layer coating increases, the contact angle will increase (Figure 4). It was found that wire mesh 300 with 14 layers of *TiO$_2$* shows the highest water contact angle compared to the other two mesh, which is 122.32^{o} (Figure 7c). This indicates that the surface becomes the most hydrophobic once it was coated for 14 times. The hydrophobicity of wire mesh 70 and 100 increases to the 34.74° (Figure 5a), 79.01° (Figure 6a), 95.22° (Figure 7a) before coating and 103.74° (Figure 5b), 109.91° (Figure 6b), 111.81° (Figure 7b) after 7 times coating, respectively. Wire mesh with 14 times coating show higher contact in comparison with uncoated and 7 times coating with 109.90° (Figure 5c), 115.74° (Figure 6c), and 122.32 (Figure 7c). Since the contact angle for mesh wire without coating shows less than 100°, they can be considered to have hydrophilic behavior. The results also indicated that the static water contact angle increased with increasing number of coating layer of the *TiO$_2$* mesh. The reason is that the mesh surfaces become rougher with the increase of the *TiO$_2$* particles deposited on the stainless steel mesh, and the water contact angles consequently becomes larger under the same hydrophobic modification condition. All the water droplets were stable and could not penetrate the hydrophobic meshes due to the negative capillary effect [17].

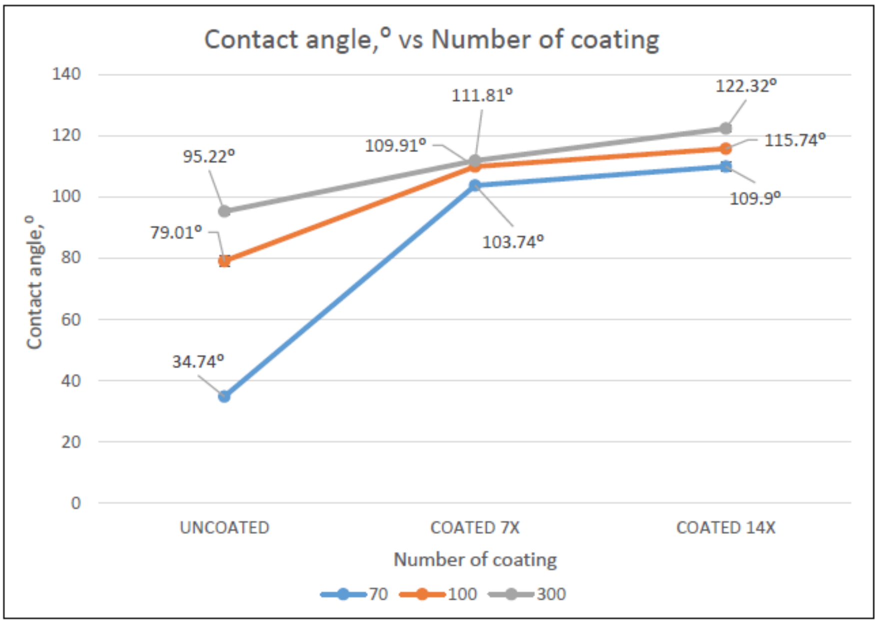


Fig. 4. Effect of *TiO₂* coating layer on contact angle as prepared mesh

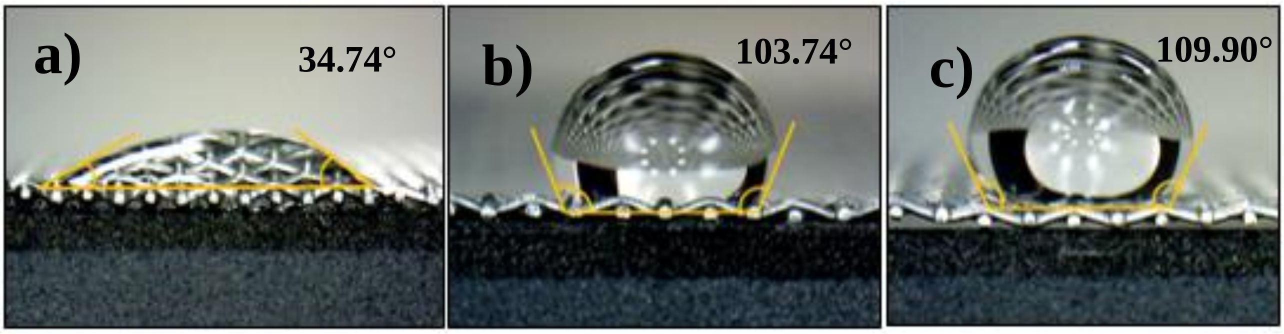


Fig. 5. Image of water droplet on wire mesh 70 a) uncoated, b) coated 7 times, and c) coated 14 times with TiO_2

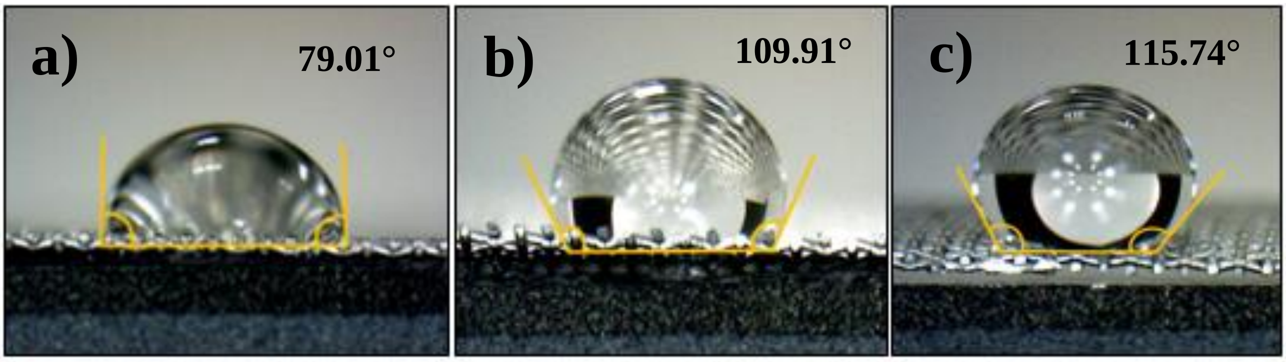


Fig. 6. Image of water droplet on wire mesh 100 a) uncoated, b) coated 7 times and c) coated 14 times with TiO_2

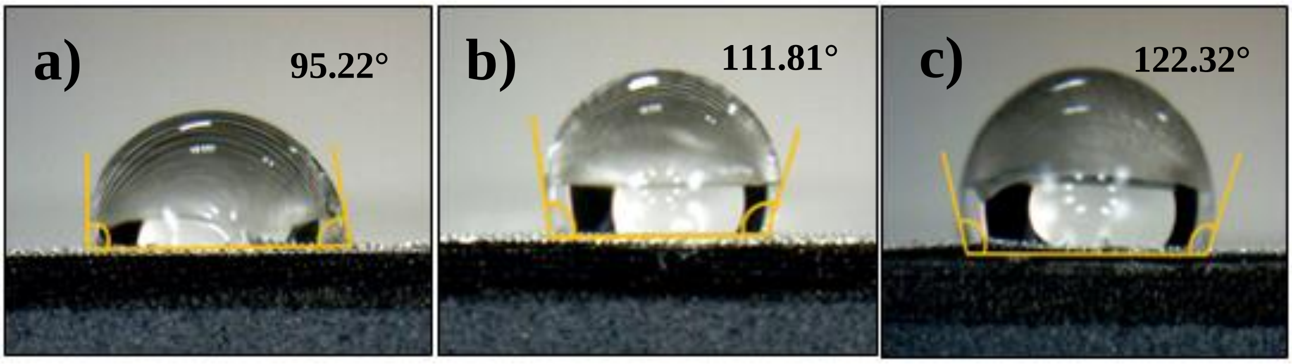


Fig. 7. Image of water droplet on wire mesh 300 a) uncoated, b) coated 7 times and c) coated 14 times with TiO_2

4. Conclusions

The analysis includes 3 variations pore size of stainless steel wire mesh and each size has 3 difference condition which are uncoated, 7 times coating and 14 times coating of layer with TiO_2 respectively. Based on this investigation, the wire mesh 300 and the coating 14 times showed the highest WCA of 122.32^0 in the hydrophobic surface category. Furthermore, this mesh also showed rapid spread and penetration of cooking oil within less than 1 second in the oleophilic surface category. All those are due to the pore size and roughness of the wire mesh surface. The more TiO_2 layers are coated, the rougher the surface of the wire mesh becomes. This is because surface wettability or hydrophobicity can be increased by TiO_2 coating.

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