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Influence of lubricant factors on static coefficient of friction for Pistia leaves surfaces and micro fiber fabrics

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KEYWORDS

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ABSTRACT

Textures of most engineering surfaces or even biosurfaces are neither isotropic nor anisotropic. Hairy structures on leaves surfaces for example have different characteristics which will affect the behavior of fluid flow. Current work on oleophilicity behavior for the case of of hairy structures and micro fiber textiles are still scare This paper describes an investigation of static coefficient of friction (COF) for lubricated and unlubricated conditions for the case of the micro fiber fabrics as well as young and mature pistia leaves. Two different types of oils namely VG68 hydraulic and palm oil were tested. The morphological structures of the samples were observed using variable pressure scanning electron microscope (VP-SEM). The kinematic viscometer has been deployed to get the kinematic viscosities of both lubricants. The oleophilicity properties were examined based on contact angle measurements. The static COF was determined by using aluminum surface of a horizontal inclined plane. The static COF was computed and the results suggest that pistia leaves have lower COF values, in the range of 0.24 to 0.37 compared to micro fiber fabrics. Hence, this indicates the potential of pistia leaves structures for engineering application specifically in tribology based technology relation to lubrication.

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1.0 INTRODUCTION

Surface texture is defined as the repetitive or random deviation from the nominal surface that forms the three-dimensional topography of the surface. Surface texture includes roughness, waviness, lay and flaws (Bhushan, 2001). Surface roughness or functional surfaces with micro textures of material with two contact surfaces condition getting much more attention in many applications either soft or hard material especially in fluid flow. In 2011, some researchers had mimicked salvinia molesta structure using silicon wafer. They attempted to obtain the retain air structure using photolithography technique and coated with hydrophobic trichlorosilane (Hunt & Bhushan, 2011). Imprinted silica sol-gel film was introduced by (Saison et al., 2008), is one of the new an attractive method to fabricate an inspired structure of the butterfly wing. The researchers claimed that the specific behaviour of the silica sol-gel allowed the surface structure to switch from superhydrophobic to superhydrophilic with the formation of pure silica structure, the nano-structured films can withstand to high temperatures more than 200°C. In another research work by Singh et al., (2016), the surface topography of lotus leaf was successfully fabricated using capillarity directed soft lithography technique to micro tribological properties like friction. This was reported that this capillarity directed soft lithography method provide fast and efficient route.

Properties of solid surfaces are vital to surface interaction because surface properties affect areas of contact, friction, wear and lubrication. In addition to tribological functions, surface properties are important in such applications like optical, electrical and thermal performance, painting and appearance (Bhushan, 2001). In engineering surfaces modification, especially in micro and nano scale, has developed as a new solution for numerous tribological constraints (Yoon et al., 2006). Many successful attempts to develop advanced functional material or device by modifying surface texturing and by mimicking natural systems in order to decrease the friction coefficient of the newly developed materials and devices (Gabriel, 2011; Rao et al., 2012).

Besides surfaces modification, there has been continuous work on lubrication advancement which is inspired by nature such as those reported in the work of Anand et al., (2017). It was reported by Saruhan (2009) and he proposed a new lubricant composition for sliding contact under high loading as is the case for mammalian joints. Mustafa et al., (2015) found that from banana skin added to a lubricant help to reduce the coefficient of friction (COF) during a tribological testings. Numerous hypotheses and observations explain the influence of different material and lubrications on the value of COF towards two contact surfaces (Wada et al., 2016; Wong & Tung, 2016). In 2007, the researchers carried out measurement of friction force as a resistance encountered by one body in moving over another and they found it was proportional to the applied load but independent of the sliding surface area (Bekir et al., 2007).

In many studies, lubrication plays an important role in dealing with friction related issues. In automotive for instance, choice of lubrication has become a critical component in advancing engine performances or even any rotary motion, where it was observed that lubricant choice has instantaneously enhanced the fuel economy while reducing emissions (Masjuki et al., 2014).

In the past, hairy structures of plant leaves surfaces have been mimicked into engineering surface applications that promote oleophilicity behaviour such as in cleaning including polishing cloths. Various cleaning cloths have been disclosed in prior art as being useful for wiping off dirt and grime, to clean and polish. Rags, cloths, paper towels and textiles are used to wipe off dirty surfaces such as kitchen counter tops, floors, desks, hands or body after shower and cars. Textiles or fabrics are used in laboratories, factories or in car repair shops to wipe off grease, oils or chemical (Hernandez et al., 2017; Pirc et al., 2016). A fabric may define as a planar assembly of fibers, yarns or combination of these element. The particular fabric selected for a given application depends on the performance requirements imposed by the end use and the desired aesthetic characteristics of the end user with the consideration of cost and price.

One of the studies used microfiber textile (TextMet) as a polishing cloth to polish the 12 discs implant in dental application with diamond paste and all the discs were completed flat (Sikora et al., 2018). In the late 90s, Hayashi (1997) had invented a polishing system for flattening the surface of a semiconductor device. The inventor claimed that, using the conventional polishing cloth with polishing agent like silica and diamond particles could cause scratches due to friction between surface substrate and polishing agent. As a solution, Nikel is typically used in polishing cloth surface treatment process to avoid similar problem and make the polishing process move smoothly.

In this study, micro fiber polishing or cleaning cloths were selected for comparison due to the desirable behaviour as absorbent applicator with oleophilicity characteristics. The selected cloths are typically used for different applications such as polishing a painted exterior surface of a car, boat, motorcycle, bicycle and the like as well as for cleaning at the kitchen counter top. The performance of lubricated and unlubricated fabrics surfaces was compared to lubricated and unlubricated pistia leaves surfaces to appreciate the effect surface structures on friction. This study provides the basis for the development of pistia leave inspired surface in future.

2.0 EXPERIMENTAL PROCEDURE

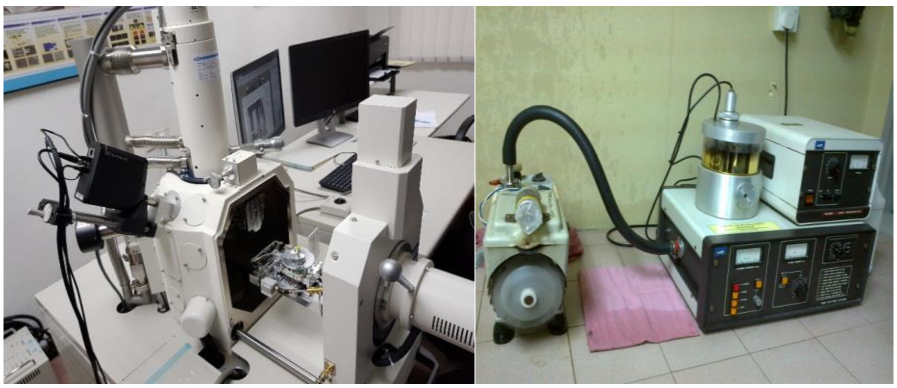
Two different maturity of pistia leaves were used which classified as young and mature leaves. The leaves were characterized based on size and colour of the leaf and two different textures of micro fiber fabrics. Two types of oil deployed were palm oil and hydraulic oil VG 68 during experiments (Diyar et al., 2014; Latif & Kasolang, 2017). The viscosity of both lubricant oils were measured by using Canon CT-500 kinematic viscometer as shown in Figure 1. The experimental procedures were performed with Cannon-Fenske glass capillary kinematic viscometers in a constant temperature bath. Two different of Fenske glass viscometers with a capillary with an inner diameter ranging from 0.46 mm to 2.65 mm and length of 90 mm for both 40°C and 100°C were performed in this study. The viscometer glass tube was suspended in a silicone oil bath whose temperature was monitored by a thermometer. The efflux time of the meniscus to pass on the desired mark was taken. A precision scientific constant temperature bath with a Micro-set Thermoregulator, in accordance with ASTM D445 was used in the viscosity determinations procedures (Noureddini et al., 1992). Generally, the kinematic viscosity values at 40°C are the basis of the ISO grades for lubricating oils in industrial usage (Jan et al., 2013). Viscosity is a fluid property representing the internal resistance to shear in a fluid layer. Typically, viscosity is measured as shear stress and shear rate, or as the time required for an oil sample to flow through a standard orifice at a given temperature. In Tribology, the behavior of the lubricant in the contact zone is affected by its viscosity (Bastian E.Rapp, 2016). The oil industry is usually given in kinematic viscosity, ν (dynamic viscosity divided by oil density), expressed in centiStokes (1 cSt = 1 mm^2/s) conventionally at 40°C and 100°C.

Figure 1: Kinematic viscometer.

The wettability of leaves surfaces was determined on young and mature pistia leaves as well as micro fiber fabrics by measuring the static contact angles of oils droplet with 2µL of volume droplet using a horizontal microscope equipped with a contact angle meter (model OCA 15EC) as shown in Figure 2 at ambient temperature. To obtain an even surface, whole leaves or parts of the leaf blade and micro fiber fabrics were affixed to sample table manual moveable with double sided adhesive tape in horizontal and precise adjustable in vertical (z-axis) via hand wheel. The liquid was injected manually on the leaves surface and left it for 10 s before the image is being captured. The sharpest possible image was captured and contact angle was captured after 10 s. Since it is very difficult to determine the exact contact angle in hairy structure, one based line was made on the surface where the liquid droplet touched. Each sample was measured for ten times at ten random locations on the samples and the average values of contact angle were calculated.


Figure 2: Scratching tester with a diamond spherical segment.

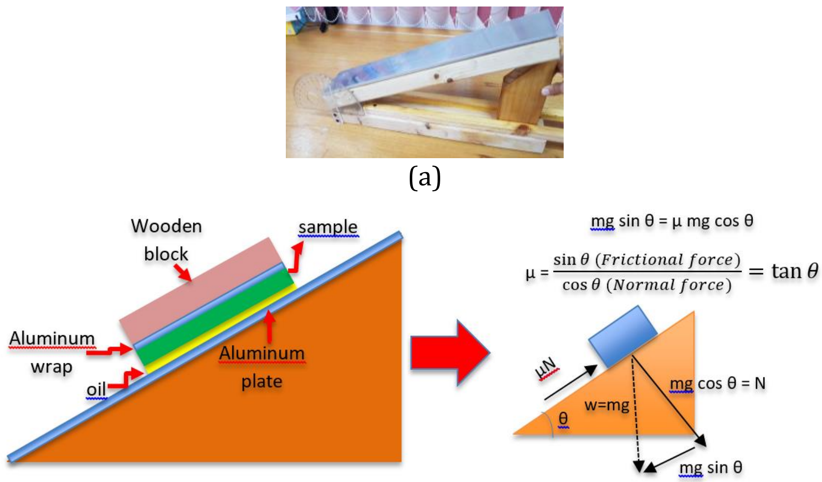
The morphological structure of two micro fiber fabrics and pistia leaves surfaces were carried out using a high resolution VP-SEM SU5000 Hitachi model as shown in Figure 3 (a). The two micro fibers were coated with thin layer of gold on its surface using Auto Fined Coater of JEOL-JFC1600 (Figure 3 (b)) meanwhile the examination of the surface topography of pistia leaves surfaces were observed without any special coating needed on the specimen. The purposes of coating of the micro fiber fabrics are to coat the non-conductive specimens with metals, efficiently and in a short time for SEM observation and analyses. Sputter coating is a standard method for preparing non-conducting or poorly conducting specimens prior to observation in a SEM. It is fully automated vacuum and sputtering the specimens after the unit on and sputtering time were selected. The chamber will evacuate and sputtering will begin automatically. Each sample was cut to size 5 mm × 5 mm and affixed to aluminum stubs with double sided adhesive tape.



(a) (b)

Figure 3: The (a) SEM machine and (b) Auto fined coater.

A bespoke apparatus (Figure 4) for measuring the static COF has been designed due to soft and fragile samples. This method was recommended by (N. Nuno & R. Groppetti, 2006) where they claimed that the method was more accurate than the prototype sliding friction tester due to good repeatability in determining the COF. This experiment was carried out by following ASTM F1677 standards. The 265g of wooden block with 4cm × 2cm × 1cm of dimension was used to fix the sample onto slide of the incline plane. The tests were performed in dry and wet conditions to examine the COF. In wet condition, two different oils were used at room temperature of 26°C ± 1°C and care was taken to avoid the possible oil suction effect. The 5ml of oil was slowly applied on the sample using a syringe. Before the experiments began, the weight of wooden block with fix samples were taken using a weighing scale. Then, the block with tapered end (45°) was manually moved forward until the inclined plane started to slide. The angle at the moment of initial movement of the samples was measured to calculate the COF of the material using Equation 2 (Dickey et al., 2011). Each experiment was repeated 5 times for establishing an average value.



(b) (c)

Figure 4: COF measurement apparatus (a) Bespoke Apparatus for COF measurement of soft materials and (b) schematic diagram for COF measurement of textile and real leaves samples with oils (c) free body diagram of relationship between COF and their forces where μ is static COF, N is normal force, m is mass of an object, g is gravitational force (9.81 m/s^2) and θ is angle of inclined plane.

3.0 RESULTS AND DISCUSSION

The morphologies of pistia leaves and two different micro fiber fabrics were observed. The two micro fiber fabrics have different structures as shown in Figure 5. Figure 5 (a) shows knitting style of texture and Figure 5 (b) shows unweaving method of fabric texture. The micro fiber fabrics exhibit a significant change in its morphology as seen in Figure 5 (a) and 5 (b). These two micro fiber cloths have tiny loops that function differently than the loops on terry cloth. They can absorb as much as six times its own weight in liquid and also great at retaining polishes and waxes (Elizabeth, 2019). Physically, both of them are very soft and gentle. They can use on hard and soft paints, glass, wheels and plastics by removing waxes and polishes. Micro fiber fabric in Figure 5 (a) shows the fiber woven in a looped weave rather than flat will be better at absorbing and hanging onto dirt and debris (Brian, 2018). Interestingly, in Figure 5(c) and 5(d), young and mature pistia leaves have different length of hairy structure on their surfaces. The hairy acrylic conical shape became longer with maturity (Latif & Kasolang, 2017). A segmenting acrylic shape at the center of cell were observed. According to (Latif & Kasolang, 2017) the adaxial surface of pistia leaves are densely covered with complex multicellular hairs. The gap function among the hairy structures may trap the dirt, liquid or debris after finishing the pistia substrate into application. The surface texture measurement like surface roughness measurement of the real pistia leaves and micro fibre fabric cannot be done due to material itself.

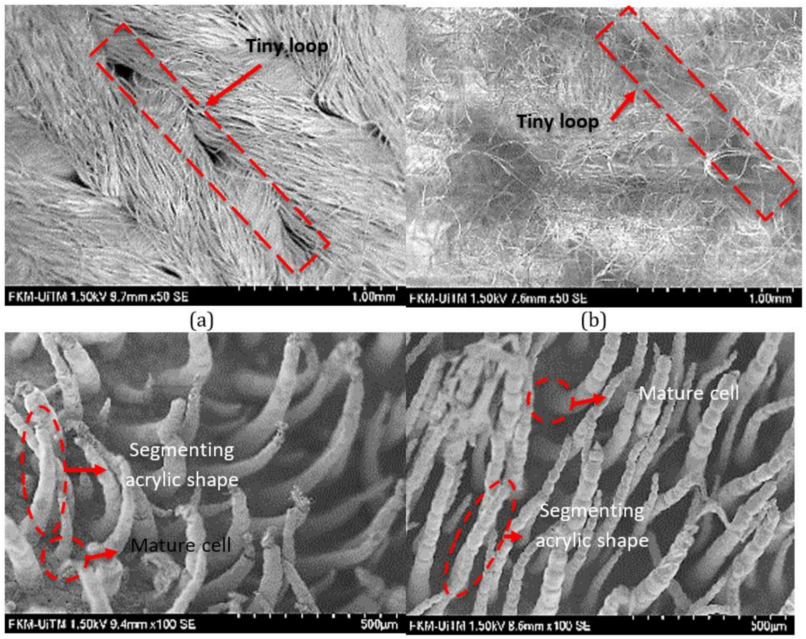


Figure 5: VP-SEM images of (a) micro fiber fabric 1; (b) micro fiber fabric 2; (c) Pistia young leaf and (d) pistia mature leaf.

The viscosity of oils used was tabulated in Table 1. In this case, viscosity is a measure of resistance to relative motion in fluid layers which is friction between fluid layers. Variations in viscosity as a function of temperature were calculated by using Equation 1. The calculated viscosity values of the oil used were 112.11 cSt and 49.32 cSt at 40°C meanwhile 19.11 cSt and 10.32 cSt for hydraulic oil VG 68 and palm oil at 100°C respectively. The higher the kinematic viscosity, the more efficient a fluid is able to transport momentum (Bastian E.Rapp, 2016) until an optimum value is reached determined by many factors including for example the operating conditions and the ratio of bearing diameter and length for the case of journal bearing. This property is often referred to as the possible medium for momentum dispersion through the fluid. A fluid with fast momentum transport will consider for more laminar flow conditions due to fact that it balances the inertia forces of the in and out flowing mass effectively (Bastian E.Rapp, 2016). In this study, hydraulic oil VG 68 gave highly viscous fluid and liquid of low density which is good candidates as a lubricant for excellent fluid flow properties during the experiment for pistia leaves and micro fibre fabrics. It is believing that viscosity is one of the factors that can prevent friction between two contact surfaces depends on application (Nikolakopoulos & Ã, 2008).

Table 1: Viscosity of lubricants.

Lubricant	Viscosity at 40°C, cSt	Viscosity at 100°C, cSt
Hydraulic oil VG 68	112.11	19.11
Palm Oil	49.32	10.32

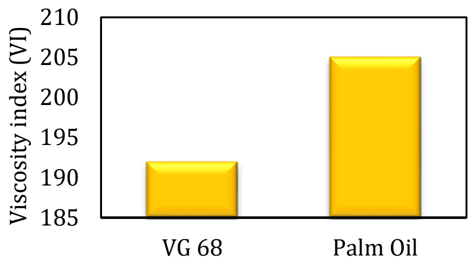


Figure 6: Viscosity index of hydraulic oil VG 68 and palm oil.

In this study, appreciation of viscosity is extended by measuring viscosity index (ASTM D2270) to appreciate the response against temperature change as shown in Figure 6. Contrary to expectations, the study found a significant difference between kinematic viscosity and viscosity index. In viscosity index, the palm oil viscosity index is higher (205) than the hydraulic oil VG 68 viscosity index (191). This is attributed to the fact that the molecular weight of palm oil, which contain triglycerides, is much more stable than that of hydraulic oil VG 68. Higher viscosity index promotes a more stable viscosity across a range of temperatures (independent to temperature) (Mohamad, 2017). This property makes the palm oil suitable for high temperature applications, typically 250 ºC and above (Diyar I. Ahmed., 2014; Zainal et al., 2018). The triglyceride in palm oil has more polar functional group than that of petroleum-based oil and hence it has higher affinity to metal surface. This property become relevant when the pistia leaves inspired texture is coated with the metallic or heat resistance materials. The polar functional groups in the triacyl-glycerol molecule promote excellent boundary lubricating properties with strong physical and chemical absorptions on the metal surface in contact include a stable protective film (Sakinah et al., 2016). Diyar I Ahmed et al., (2014) claimed that higher viscosity index in vegetable oil can help in counter-acting extreme thickening than mineral oil. Thus vegetable oil can be used as a base stock for lubricants.

$$\nu = Ct \tag{1}$$

Where;

ν = kinematic viscosity, mm^2/s
C = viscometer index
t = flow time, s

The contact angle measurements as shown in Figure 7 prove that all the samples have shown as oleophilicity behavior due to the contact angle having values below than 90° when they were tested using VG 68 and palm oil lubricant. Fabric 1 and Fabric 2 gave 12.2° and 11.7° respectively while pistia young and pistia mature recorded 10.9° and approximately to 0° respectively.

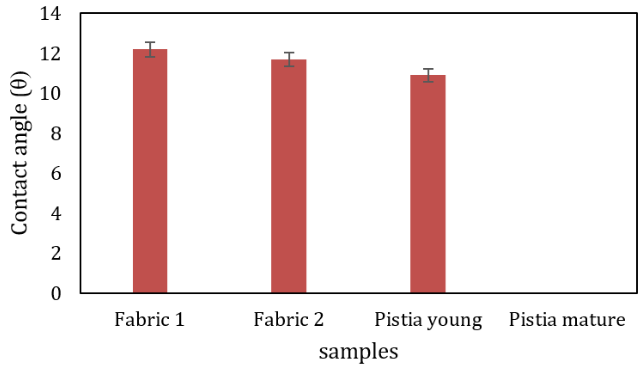


Figure 7: Contact angle values of the samples

Results of COFs calculated using equation 2 are presented in Figure 8. This equation was derived from an equation F = μN where F is a static friction force, μ is a coefficient of static friction between an inclined plane and object and N is normal force. The derivation of the equation can be seen in Figure 4 (c). Based on the results as shown in Figure 8, COF values for un-lubricated samples are higher than that of the lubricated samples in the range of 0.30 until 0.58. This is as expected due to relatively high friction occurred between aluminum inclined plane plate and the morphological surfaces of the samples. VG 68 hydraulic oil gave lower COF values than palm oil due to additives added in the oil for effective performances (Diyar I. Ahmed., 2014). The contact angle values support this finding where giving superior oleophilicity behavior towards VG 68 hydraulic oil and pistia leaves.

Another important finding is that the viscosity did affect the COF values. Based on the results in Table 1 and Figure 8, COF values decrease when the viscosity of oil increases. A strong relationship between viscosity and friction has been reported in the literature where the lubricant is thick enough to prevent surfaces contacts (Nikolakopoulos & Ã, 2008). However, it was believed that a variety of factors can affect the slide angle measurements including abrasion, coating, varnishes, printing and surprisingly humidity as well (The TMI Group of Companies, 2015). The range of the COF values of VG 68 hydraulic oil is from 0.22 to 0.38 which is lower than those of palm oil for all cases of surfaces. Overall, pistia leaves have better COF result values than micro fiber fabric does. This warrant the potential of pistia leaves surfaces to be mimicked for polishing cloth application. It was found that surface textures had significant effect on friction even though the COF did not vary much with the contact angle values in the present test range.

$$\mu = \tan \theta \tag{2}$$

Where;

μ = COF

θ = initial sliding angle

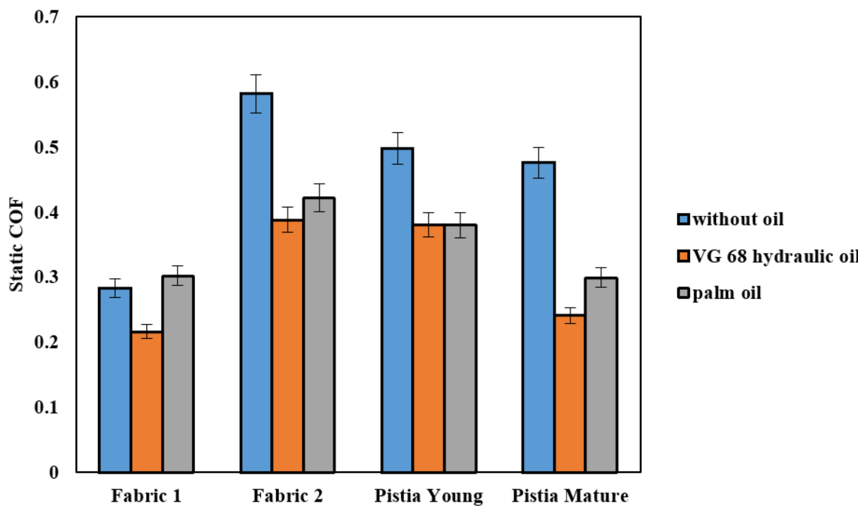


Figure 8: Static coefficient of friction of fabric 1, fabric 2, young and mature pistia leaves.

4.0 CONCLUSION

This study is about biomimetic inspired structured surfaces for fluid flow application. Young and mature pistia leaves were used to investigate the oleophilicity characteristics. For comparison purposes, two different structures of commercial fabrics were also deployed. Palm oil and hydraulic VG 68 oil were used as lubricants. The viscosity of hydraulic oil is higher than that of palm oil and for the viscosity index, it is vice versa. It was also found that the COF values of pistia leaves were lower than those of micro fiber fabric in the range of 0.24 to 0.37 including cases in the absence of oil. Hydraulic VG68 oil has shown the lowest COF values and required the smallest angle to drag down on the inclined plane.

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