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Alkaline Cleaning-in-Place of Pink Guava Puree Fouling Deposit Using Lab-scale Cleaning Test Rig

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Abstract

Cleaning-in-place (CIP) of pink guava puree (PGP) fouling deposits is not well known compared to dairy deposits which is well established. Lab-scale cleaning test rig has been used to investigate the cleaning performance of PGP deposits. Removal mechanism during alkaline-based cleaning of PGP deposits were investigated using NaOH concentrations (1.0 wt% -2.0 wt%), temperatures (35 - 70°C) and fluid velocities (0.6-1.5m/s) over a range of Reynolds number ($Re = 4 \times 10^4 - 1.8 \times 10^5$). Cleaning rate was quantified by measuring the remaining area of the deposits at sample holder at every 1min. The efficient CIP process for PGP fouling deposit can be obtained at 1.5m/s, 70°C, with concentration of (1.0 - 2.0wt%).

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Keywords: Cleaning-in-place; cleaning test rig; fouling deposit; fouling; pink guava puree; test section

1. Introduction

Fouling is critical in food industries. Bott (1995) defined fouling deposit as the formation of unwanted deposit on the surface of processing equipment. The formation of fouling deposit inside the food processing equipment surface affects the process efficiency, and thus it increase the plant operation cost significantly. Fouling deposit cause contamination to the food fluid and reduce the product quality and hygiene. Thus, cleaning is a must in food

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industries. Many studies have been done in exploring the factors that caused fouling deposit formation on the food processing equipment (Liu et al., 2006a; Liu et al., 2006b; Gilham et al., 1999; Gilham et al., 2000; Christian and Fryer, 2006). However, fouling deposit research on Malaysia food productions (i.e. tropical fruit juices, tropical fruit purees, baby food, chilli sauce) lags behind research on fouling deposit in Western countries (mostly for dairy products). In this work, pink guava puree (PGP) fouling deposit was used as the physical fouling model. Lim and Khoo (1990) indicate that Malaysia is among the top producer of PGP in the world.

In food industry, cleaning-in-place (CIP) is a common practice, which a series of rinsing steps was performed using in-situ method, without dismantling the process equipment (Tamime, 2008). CIP is an important process in maintaining the hygiene aspect in food processing plant. Single stage alkaline-based cleaning detergent was used in many cleaning studies. For instance, Law et al. (2009) and Liu et al. (2006b) used sodium hydroxide. While Ho et al. (2010) used sodium oxide.

High turbulence fluid velocity of cleaning fluid is one of the CIP design principal to design an effective CIP process. Turbulent flow ($Re=4 \times 10^4$ to 1.8×10^5) of cleaning fluid was used in this study to remove the PGP fouling deposit. Tamime (2008) stated that CIP process involves 8 stages or cycles which are; (1) removal of gross debris, (2) pre-rinse, (3) detergent recirculation, (4) intermediate rinse, (5) second detergent recirculation (optional), (6) intermediate rinse, (7) disinfection and (8) final rinse. However, different fouling deposit has different characteristics which need different CIP process. A CIP process is designed differently for each processing plant, in order to avoid prolonged downtime, overuse of water and chemical wastage during cleaning.

Lack of references on the PGP and its fouling deposit has given a difficulty to design a suitable CIP process. Thus, the aims of this work were (1) to obtain physical fouling deposit model of PGP fouling deposit and (2) to investigate the cleaning performance from the cleanability experiments. The physical fouling deposit model of PGP fouling deposit is developed for this work, in order to ensure that the fouling deposit used is similar, uniform and reproducible for every cleanability experiment. In this work, a monitoring device for removing the fouling deposit, namely lab-scale cleaning test rig, which provides direct monitoring at the fouling area, was used in the cleanability experiments.

2. Lab-scale cleaning test rig

Cleaning was performed using the lab-scale cleaning test rig of Tew et al. (2012), which allows real-time monitoring of the removal activities; hence the effect of chemical reaction and fluid mechanics on the cleaning performance can be deduced. Within the rig, the cleaning fluid flows across a sample holder which was fouled with PGP. Cleaning time was taken when the area profile reach 100% clean. The surface area of the sample holder covered with PGP fouling deposit is 675 mm^2 . PGP was prepared as described in the next section. The sample holder was inserted into the test section, and then the test section was attached to the lab-scale cleaning test rig. The schematic diagram of the test section is shown in Fig.1.

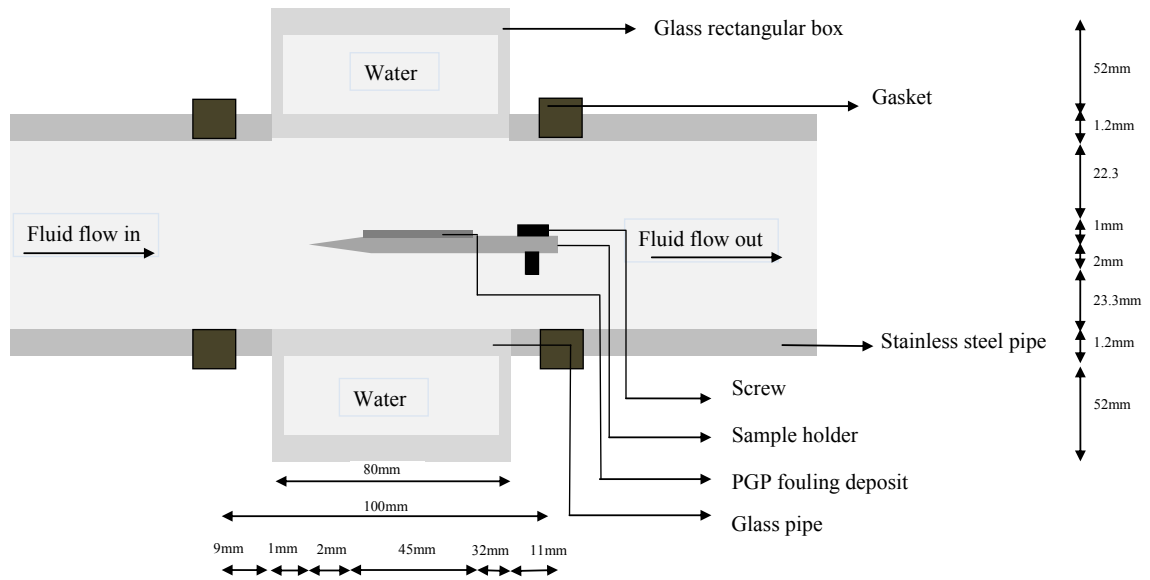


Fig. 1. Schematic diagram of test section.

This rig resembles a common CIP station (Lelièvre et al., 2002; Heldman and Lund, 2007) and was designed to test the effect of CIP condition on different deposit. The CIP performance is determined by measuring and monitoring the remaining fouling deposit area at the sample holder. The design of this cleaning test rig (Fig.2) was based on the general procedures developed for recirculating water tunnel design, presented by Sargison et al. (2009). The cleaning fluid at different concentrations of NaOH (1.0-2.0wt%) and temperatures (35–70°C) was prepared in a chemical tank before being pumped into the test section. In this work, an alkaline-based detergent AC 101 was donated by ECOLAB Malaysia. It is a common cleaning chemical, which is utilized in the cleaning of food plants. A video camera was placed on top of the test section to record the changes during cleaning. Cleaning fluid is then recycled to the chemical tank.

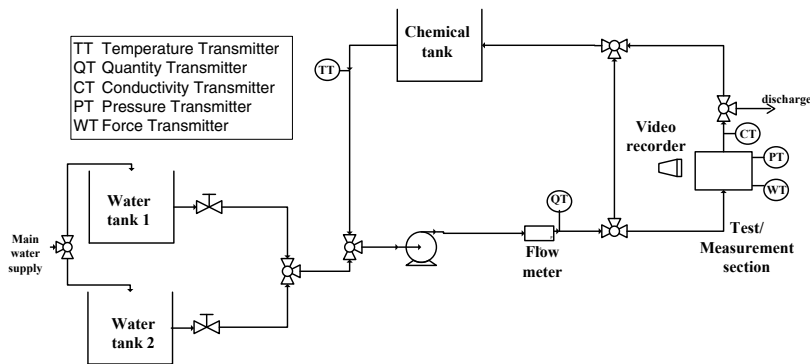


Fig. 2. P&ID of lab-scale cleaning test rig.

3. Cleaning experiment

3.1. Preparation of fouled sample holder

The physical fouling model of PGP fouling deposit was prepared by using ex-situ method. The PGP fouling deposit was prepared by adapting the method, proposed by Liu et al. (2006a) and Liu et al. (2006c). The PGP was baked in the convective oven for 1 hour at 100°C. The baking process dried the PGP and baked the PGP into a hard form which is difficult to remove. Initially, the PGP fouling deposits were formed by placing the (2.0 g) PGP onto the surface of a sample holder (1.5 cm width and 9.0 cm long). The PGP was spread evenly on the sample holder 1.5 cm width x 4.5 cm length, to only consider the visible area of the test section. After 1 hour of baking, the sample holder was put in a desiccator for 10 minutes, before it was weighed. Sample holders were weighed before and after the fouling experiment, respectively to obtain the PGP fouling sample mass. Fig. 3 shows the average value of PGP deposit mass (collected from 3 batches, each of 5 sample holders) as 0.22 ± 0.01 g. The mass of the deposit samples slightly varied (about 5%) from batch to batch and within batches.

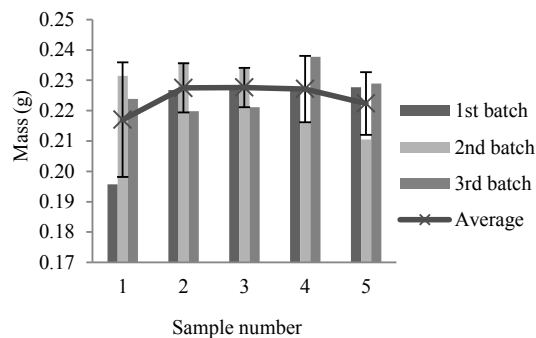


Fig. 3. Mass of samples in 3 batches of preparing PGP fouling deposits (5 samples in each batch).

3.2. Cleaning Monitoring Techniques

Cleaning progress was quantified by measuring the remaining area of PGP fouling deposit on the sample holder. The sample holder was declared 'clean' when 100% of fouling deposit was removed. If the cleaning does not reach 100% clean after 180min, the cleaning process is considered not clean. A video recorder (Panasonic, HDC-SD100) was used to film the cleaning progress. The video was then converted into 1 minute interval images by using 'Free Video to JPG Converter' software. Then, the images were processed by ImageJ program to measure the cleaning area. The ImageJ software was spatial-calibrated where the length scale was calibrated against a known length in the cleaning images. In this case, the known length is the width of the sample holder (1.5cm). Then, the images were analysed to measure the remaining area of PG fouling deposit on the sample holder for every minute. The analyze data was used to generate the cleaning profile.

4. Results and discussion

A series of experiment were carried out to study the effect of various process parameter namely concentration, temperature and fluid velocity related to the fouling deposit removal. The combined influences of the following conditions were also investigated:

- Temperature (35, 50 and 70°C)
- Concentration (0, 1.0, 1.5 and 2.0wt% NaOH)
- Fluid velocity (0.6, 0.9, 1.2 and 1.5m/s)

4.1. Effect of concentration

According to Liu et al. (2007) the adhesiveness strength of egg albumin deposit decreased as the NaOH concentration increased from 0% to 2%. The findings from Liu et al. (2007) support this current work where the cleaning time decreased as the NaOH concentration increased. Unclean situation (Fig. 4(a)) is observed at 35°C (ambient temperature) for all cleaning concentration (0wt%-2.0wt%NaOH). Thus, it shows the chemical reaction dependency to temperature. As temperature increase, the kinetic energy of the particles increased thus initiating collisions between the particles. Hence, cleaning reaction performed better at higher temperature and this is shown for cleaning at temperature of 50°C and 70°C (Fig. 4(b) and Fig. 4(c)).

Fig. 4(b) shows that cleaning time is decreased from 1.5wt% NaOH to 2.0wt% NaOH at low velocity (0.6m/s). As cleaning concentration increased, the cleaning time decreased from 170min to 96min. As concentration increased, chemical reaction improves by increasing the amount of particle-particle collisions. Thus, the effect of chemical reaction clearly weakens the intermolecular forces and increase cleaning efficiency. At cleaning temperature of 70°C, at each velocity, the effect of velocity is not significant as cleaning performance is greatly influence by the cleaning chemical effects (Fig.4(c)). This demonstrates how the effect of chemistry exceeds the physical factor in this temperature. Cleaning effectiveness is highly depended upon the detergent added due to the observed unclean situation at all the temperatures used in the absence of a detergent. Thus, this shows that cleaning solution performed better than water as a cleaning agent.

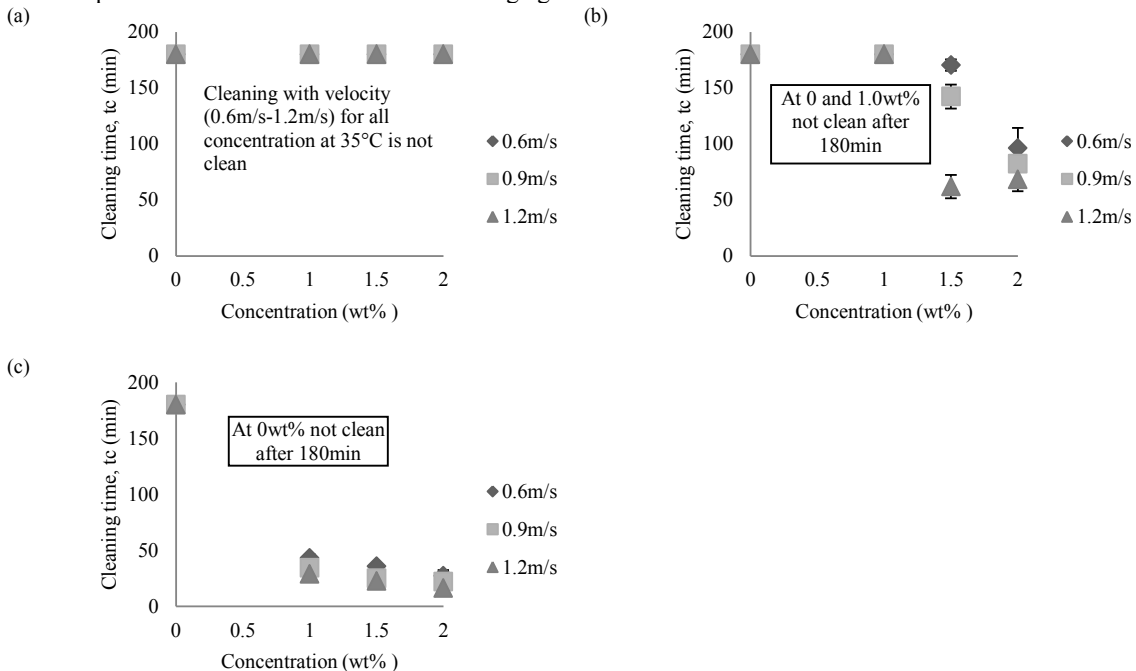


Fig. 4. The influence of cleaning chemical concentration towards time to clean of PGP fouling deposit at flow temperature of (a) 35°C (b) 50°C and (c) 70°C

Ho et al. (2010) stated that alkaline detergent allows a great driving force for chemical diffusion and increase the cleaning rate significantly. Cleaning profile performed at 35°C and 0.6m/s fluid velocity with and without alkaline detergent (1.0wt% NaOH) is investigated. The fouling deposit is gradually removed (Fig. 5(a)) when no alkaline detergent is added into the cleaning solution. In the first 9min, 17% removal was observed where removal occurred every minute of cleaning. Then the fouling deposit was removed step by step until 180min of cleaning time, where the PGP fouling deposit removal occurs on every 7 – 35min. After 180min, only 92% fouling deposit was removed. The cleaning rate increased significantly (Fig. 5(b)) when alkaline detergent is added into the cleaning solution. The

rapid cleaning observed and removed 83% of deposit in first 13min of cleaning. Thus, it agrees with Ho et al. (2010) as the concentration increased the cleaning rate is also increased. However both conditions (with and without chemicals) unable to reach 100% clean level as there is less than 8% fouling deposit (debris) remaining on the sample holder.

In this cleaning condition of 35°C and 0.6m/s fluid velocity (Fig. 5(a) and Fig. 5(b)), a 1.7mm thickness of laminar boundary layer formed on the sample holder surface. As cleaning fluid pass over the sample holder (a stationary surface), the fluid touching the surface is brought to rest (fluid velocity =0m/s) by the shear stress τ_0 at the wall. As the fluid moves over the sample holder, the velocity will increase gradually from the sample holder surface to a maximum in the main stream of the flow (original fluid velocity), which is 0.6m/s in this case. This region is called the boundary layer where the velocity profile in the flow due to the shear stress at the wall (Garde and Mirajgoaker, 1977). The thickness of the debris attached on the sample holder surface is less than 1mm. The fluid velocity on the surface at this region is almost zero (the fluid velocity is less than 99% of the "free stream" velocity (the velocity in the middle of the pipe)). Thus, the fouling deposit at this region is difficult to be removed. Therefore, any cleaning experiment with debris attached on the sample holder cannot achieve 100% clean.

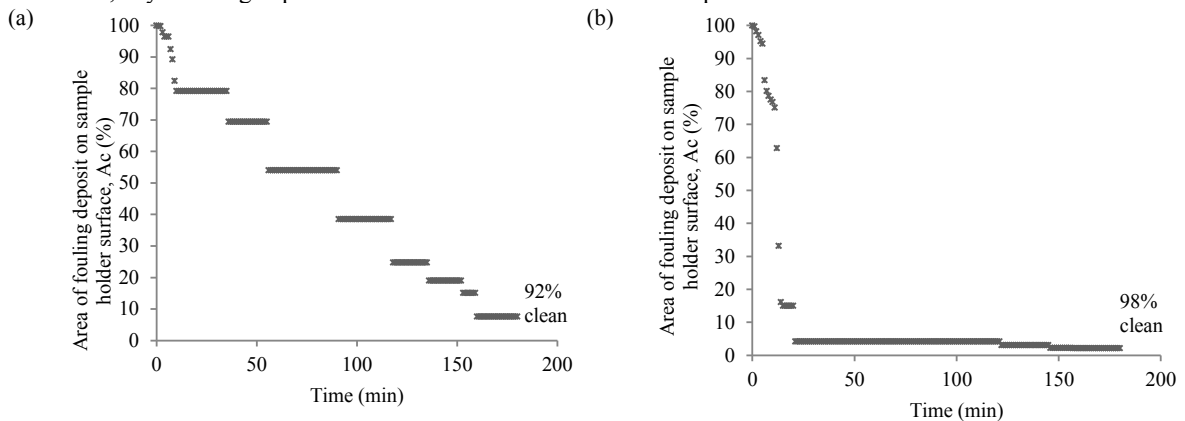


Fig. 5. Cleaning profiles of PGP fouling deposit, based on remaining area of fouling deposit at 35°C and 0.6 m/s with (a) pure water (0wt% NaOH) and (b) 1.0wt% NaOH.

4.2. Effect of temperature

Cleaning performance was greatly improved when temperature is increased. Fig. 6 shows that the removal percentage increased significantly from 35°C to 50°C. The results are supported by the cleaning time results in Fig. 7. Cleaning that took more than 180min to reach 100% cleaning is considered not clean and the percentage of removal is taken at 180min point. At cleaning temperature of 35°C, the system was not cleaned even after 180min at all different chemical concentration. At 1.2m/s, as temperature increased from 35°C to 50°C, cleaning time for a concentration of 1.5wt% NaOH changed significantly from not clean to clean and it took 62min to remove the fouling deposit. At 50°C, the concentration effect is less significant as the time to remove fouling deposit for cleaning experiment at NaOH concentrations of 1.5wt% NaOH and 2.0wt% NaOH are approximately the same (62min and 68min respectively). The results show that the reduction of cleaning time when the solution temperature is increased from 50°C to 70°C is 68min to 16min (2.0wt% NaOH). The chemical is more effective at high temperature. The results show the same pattern for concentration of 1.0wt% and 1.5wt% NaOH. However, even at high temperature (70°C), cleaning by water alone only produces 99% clean in 180min and this is considered not clean. Thus, chemical is needed to improve cleaning effectiveness. Shorter cleaning can be obtained if the cleaning temperature is increased to more than 70°C. In a cleaning study of coconut milk fouling deposit, performed by Law et al. (2009), shortest cleaning time (10min) was obtained using cleaning temperature of 80°C. However Law et al. (2009) results applied for laboratory work only. In this current work, the highest temperature used is 70°C because this is the maximum temperature been utilized widely in the industry. This is due to the economical aspect where

heating utilize energy and utility. Previous research has shown that after 70°C there are no significant changes on the cleaning performance. Thus, 70°C was chosen as the highest cleaning temperature for this work.

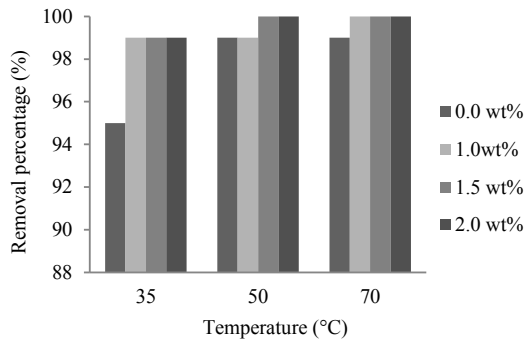


Fig. 6. Percentage of PGP fouling deposit removal varies at different temperature and at fluid velocity 1.2 m/s.

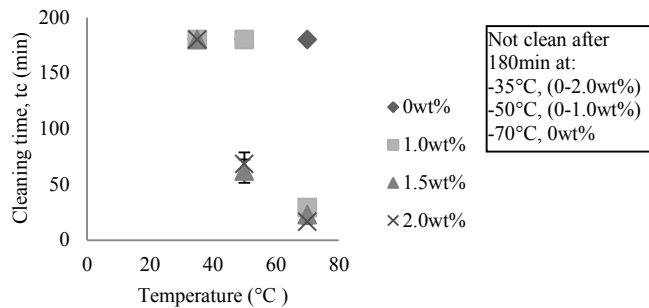


Fig. 7. The dependence of cleaning time of PGP fouling deposit on flow temperature at fluid velocity 1.2 m/s

4.3. Effect of velocity

One of the main principles in designing an effective CIP process is to use a high turbulence flow velocity. Compared to laminar flow, turbulent flow creates thinner boundary layer on the equipment surface. Thus, turbulent flow gives flat velocity profile which creates an effective cleaning on the surface. However, laminar gives streamline flow where the faster velocity is concentrate at the centre of the pipe and produce less effective removal of fouling deposit from the surface.

The PGP fouling deposit is classified as carbohydrate-based fouling deposit. Ab. Aziz (2007) stated that carbohydrate-based fouling deposit can be cleaned by water alone but the cleaning performance is not efficient. Cleaning by using water alone involves high temperature and high fluid velocity to clean the fouling deposit. In this work, the results have shown that short cleaning time can be obtained when the cleaning condition is set at high velocity (1.5m/s). For instance, only 12min was needed to remove the deposit at 70°C and 1.5m/s. However, experimental results at (1.0wt%-2.0wt%), were unable to record, as the visibility was restricted due to bubbly effect caused by the reaction at high flow rate. However, we can deduce that complete removal occurred simultaneously since complete cleaning was achieved for cleaning without chemicals.

Fig. 8 illustrates the effect of different fluid velocity on cleaning time at temperature of 50°C. The cleaning time decreased as the fluid velocity increased. At fluid velocity of 1.2m/s, the cleaning time does not change significantly for NaOH concentration at 1.5wt% and 2.0wt% (62min and 68min, respectively). Thus indicates that effect of fluid velocity is more significant than the effect of chemical. In Fig. 9, cleaning with water alone at all temperature (35°C to 70°C) for cleaning below 1.5m/s could not produce 100% clean. However, 100% removal of fouling deposit by using water alone is possible at high fluid velocity (1.5m/s). Moreover, at high fluid velocity, the cleaning time is not influenced significantly by the temperature. As shown in Fig. 9, the cleaning time reduce to 16min, 14min and 12min for cleaning at 35°C, 50°C and 70°C respectively.

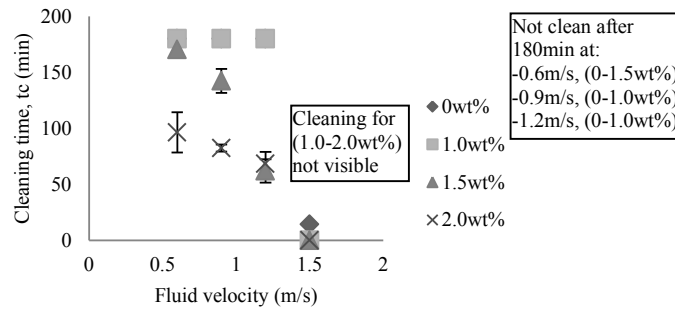


Fig. 8. Effect of fluid velocity on time to clean of PGP fouling deposit at flow temperature of 50°C

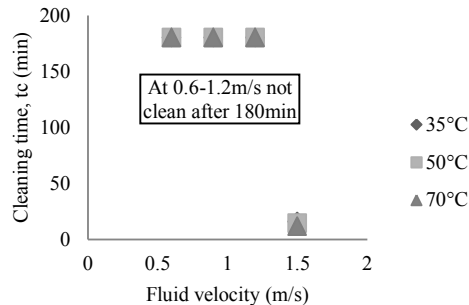


Fig. 9. Effect of fluid velocity on time to clean of PGP fouling deposit at flow temperature of pure water without NaOH concentration added.

5. Conclusions

In this work, PGP fouling deposit was used to model the physical fouling. Temperature and fluid velocity were found to be the main important parameters. Cleaning was significantly improved when the cleaning temperature was increased for cleaning at velocity of (0.6 to 1.2m/s). However, at temperature of 50°C, the effect of concentration is less significant as the cleaning time obtained at 1.5 wt% and 2.0wt% of NaOH are almost same. At fluid velocity of 1.5m/s, cleaning performance is dominated by velocity effect. Cleanability experiment performed without chemical at fluid velocity of 1.5m/s, can remove 100% PGP fouling deposit from the sample holder. However, the results obtained might not be sufficient, as the area of PGP fouling deposit used in this work is too small, compared to the industrial fouling deposit. In this work, the acceptable cleaning parameter can be considered at 1.5m/s, 70°C and with chemical concentration of (1.0, 1.5 and 2.0wt%). Thus, findings from this study can benefit PGP industry in Malaysia. Suitable CIP process can be utilized in the PGP industry.

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