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Decanter system as mechanical treatment for enhancing seawater feed quality at Sabiya power generation and water desalination plant

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ABSTRACT

Long-term performance of power generation and water desalination equipment depends on proper seawater quality. At Sabiya power generation and water desalination plant (SPDP), the seawater quality is very high in turbidity because of high content of silt and sand. Currently, the quality of seawater at SPDP is causing some inconvenience to the operation and maintenance of the station's equipment. This paper is aimed at assessing the viability of enhancing seawater quality for thermal and membrane desalination processes at SPDP using the pilot-scale decanter centrifuge unit as mechanical treatment. This unit has the potential to substantially lower the silt and sand concentration to an acceptable level, allowing the use of seawater safely as feed for membrane and thermal desalination units, as well as for power generation equipment. The experimental results indicated that the decanter centrifuge system is a viable mechanical process for improving the quality of the SPDP seawater feed. The system was able to treat 100% of seawater feed, with a 99.6% availability. The separated silt and sand by the decanter centrifuge unit is coming out as a fine dry powder from the solid side compartment, which can be collected and transferred out of the SPDP station. In addition, the results showed that as flow increases, the power consumption decreases, which give an indication that the power consumption for treating seawater utilizing decanter centrifuge with a bigger capacity will be in an acceptable range.

Keywords: Decanting centrifuge; Silt; Water quality; Turbidity

1. Introduction

Desalination is the most important and viable source of fresh water in Kuwait and the Arabian Gulf Cooperation Council countries. The multistage flash distillation and the reverse osmosis (RO) technology are the backbone of seawater desalination in Kuwait. Scale formation is a major and serious problem, often encountered during the operation of the aforementioned desalination plants, which leads to a reduction in plant efficiency, lowering distillate productivity, extensive maintenance, higher steam consumption, an increase of product water cost and lowering the availability of the plant due to cleaning and regeneration of heat transfer surfaces [1–3].

Seawater feed for Sabiya power generation and water desalination plant (SPDP), the largest plant in Kuwait contains high concentrations of silt and sand, which affect the performance and maintenance of the power generation and water desalination equipment (Fig. 1). As presented in Fig. 2, dredging is frequently used for removing silt and sand in order to keep the seawater intake at SPDP station open for continuous operation, which in fact, costs Kuwait millions of dollars every year. It is very difficult to obtain at SPDP measures below 6 silt density index (SDI), which is an indicator of a very bad quality seawater feed for RO desalination units, knowing that good quality should have an SDI of below 3. Another measure for water feed quality for RO is an acceptable nephelometric unit (NTU) turbidity level of 1–5 [4]. A previous study carried out by the Kuwait Institute for Scientific Research (KISR) indicated that the turbidity of the seawater at SPDP is very high and on an average, it is more

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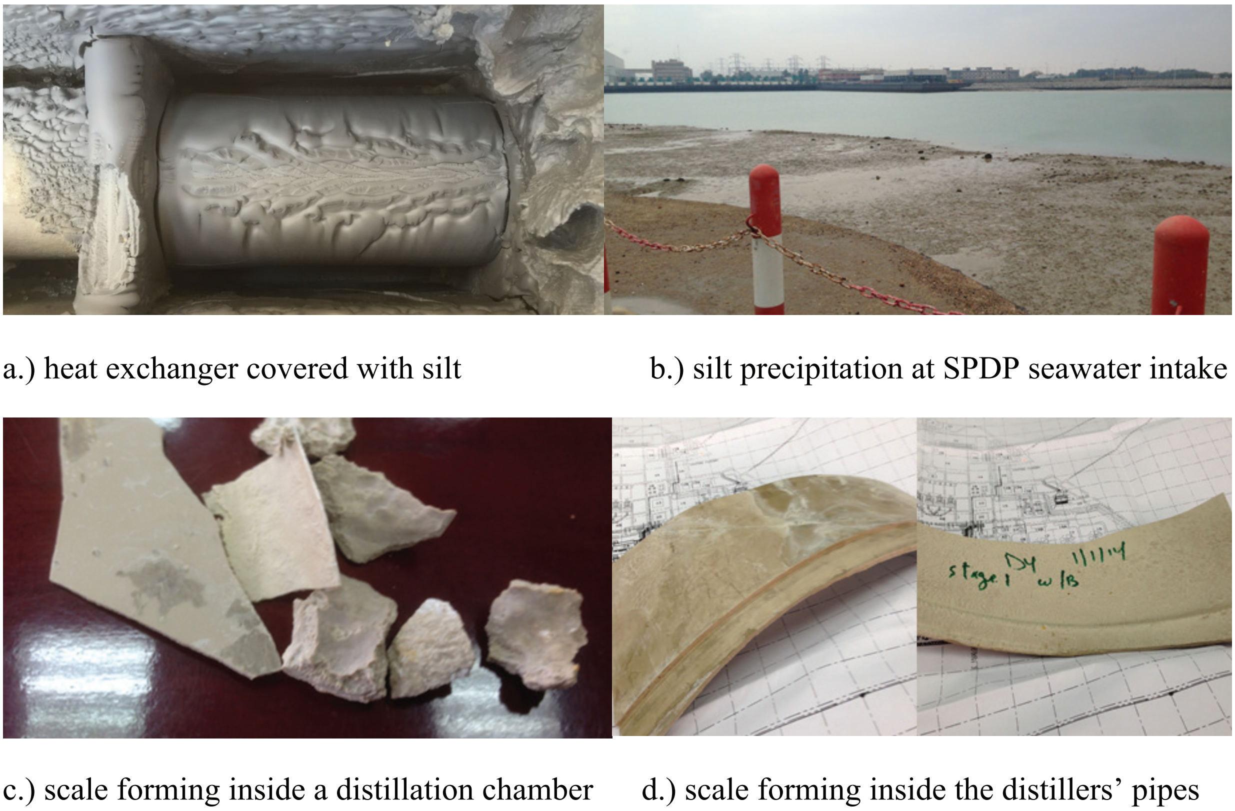


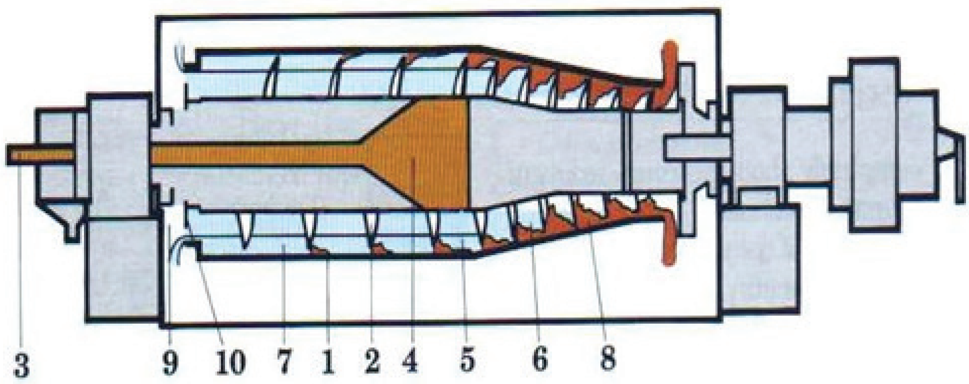
Fig. 1. Damages that usually occur at SPDP.

Fig. 2. Dredging process inside SPDP seawater intake.

than double the turbidity of the seawater at Az-Zoor North [5]. A recent study carried out by KISR [6,7] also indicated that the turbidity values of the seawater intake at SPDP can reach values that exceeds 974 NTU. This quality of seawater is causing serious problems to SPDP and definitely cannot be used for seawater desalination by the RO. Therefore, stringent pretreatment to improve the quality of seawater feed at SPDP by reducing silt and sand must be applied.

Water containing a high concentration of silt and sand can be treated through several technologies including precipitation, centrifugation, hydrocyclone treatment, conventional coagulation/flocculation, membrane separation and other processes. The simplest and direct treatment is to separate the silt and sand from seawater by using accelerated gravitational forces achieved by a rapid rotation known as centrifugation/hydrocyclone [6,7]. Hydrocyclone belongs to a class of washing classifying devices that separate solids from a fluid stream [8]. The hydrocyclone converts the initially linear motion of the seawater into continuously varying angular motion, thereby subjecting the dispersed particulates to centrifugal acceleration and enhancing the rate of settling of silt or sand according to their size, density and shape. More details regarding the hydrocyclone are described in the literature [9–11]. On the other hand, centrifuges are machines using the centrifugation principle and are used to separate different products or materials in a liquid. There are many available types of centrifuges (basket centrifuge, disc centrifuge, nozzle bowl centrifuge, solid bowl centrifuge, chamber bowl centrifuge, pusher centrifuge and decanter solid bowl centrifuge) and different theories on the separation of solid phase from liquid phase that are described in detail in the literature [11–19]. The focus of this study will be on the decanter centrifuge type. The decanter centrifuge separates a suspension into a solid phase and a liquid phase in a continuous process. The separation is achieved by rotating the entire centrifuge at a high speed. The separated solid is transported to the solids discharge port by the screw conveyer which rotates at a speed that is slightly different from that of the bowl. The decanter centrifuge system is designed from the beginning to handle significant solid concentration in the feed suspension. The system can achieve quite good degrees of clarification of the liquid concentrate, although a complicated piece of machinery embodies a simple principle [11]. As can be seen in Fig. 3, the decanter system consists basically of a horizontal cylindrical bowl (1) rotating at a high speed, with a helical extraction screw (2) placed coaxially. The screw perfectly fits the internal contour of the bowl, only allowing clearance between the bowl and the scroll. The differential speed between the screw and scroll provides the conveying motion to collect and remove the solids, which accumulate at the bowl wall. The product to be treated (3) is introduced axially into the unit by an appropriate distributor (4). It is propelled into the ring space (5) formed by the internal surface of the bowl and the body of the scroll. The separation process basically takes place inside the cylindrical section of the bowl. The relative velocity of the scroll pushes the settled product (6) along into the bowl. The conveyance of the solids into the length of the cone enables the sediment to pass out of the clarified liquid phase. As the feed is continuous, a liquid level (7) is established in the unit following a cylindrical surface that constitutes the internal surface of the liquid ring. Once the solids have passed out of the liquid ring, the remaining section of the cone all the way up to the ejector provides the final draining: this section is known as the drying zone (8). The clarified liquid (9) is collected at the other end of the bowl by flowing through the adjustable threshold (10), which restricts the liquid ring of the unit. A cover that enables the clarified liquid as well as sediments to be collected protects the rotor. The decanter operates mainly by sedimentation, a process causing the separation of suspended solids by virtue of their higher density than the liquid in which they are suspended. If the density difference is higher than the gravity it may provide sufficient driving force for the separation to occur in a reasonable time. If the density difference is small, or the particle size is very smaller, then gravity separation would take too long, and the separation force must be increased by the imposition of centrifugal forces many times that of gravity alone. The advantages of the decanter are its wide range of potential use, coupled with its continuous operation, its ability to accept a wide range of feed concentrations and its availability in a wide range of feed capacities [11,18,20].

KISR conducted a study aiming to enhance the seawater quality by removing/reducing silt and sand from SPDP using a decanter centrifuge and hydrocyclone units [6,7]. In this study, three tests were carried out using seawater at SPDP as feed to hydrocyclone unit utilizing different cone diameters of 10, 8 and 6 mm. Results showed that the unit was able to remove and/or reduce silt and sand by about 10%, 16% and 8.5%, respectively. This gave a clear indication that



1) horizontal cylindrical bowl 2) screw 3) seawater feed 4) distributer 5) space between bowl and screw 6) settled silt 7) level of seawater 8) drying zone 9) clarified seawater 10) adjustable threshold.

Fig. 3. Cross-sectional view of centrifuge system.

this system is not suitable for removing and/or reducing silt and sand from the seawater intake at SPDP. In addition, four preliminary tests were carried out in the aforementioned study using four different overflow circular slots located at the decanter centrifugation unit liquid compartment side and they are: fully open, 25% closed, 50% closed and 75% closed. During conducting the fully open and 25% closed tests, no discharge was produced from the solid side compartment. Results showed that when the overflow circular slots were fully open, 25% closed and 50% closed, the decanter system was able to remove silt and sand from seawater about an average of 60%, 70%, and 65.5%, respectively. However, for tests carried out using slots with 75% closed, results showed that the decanter system was able to remove silt and sand from seawater about 80%–90% without filter and reached 99% with filter. Results obtained in the aforementioned tests were promising when compared with the hydrocyclone unit, considering the problems encountered during the test periods such as the gearbox, polarity/direction of the bowl and screw motors and the instability of the feed water quality at SPDP. The aforementioned problems caused frequent stoppages to the decanter centrifuge unit leading to lower the availability of the unit.

After rectifying the aforementioned issues, the optimal operating conditions were determined. Accordingly, the decanter centrifuge unit was tested under the following operating condition: bowl rotation speed of 2,500 rpm, the speed difference between a bowl and screw of 35 rpm, seawater feed flow of about 3.5 m^3/h, and the four overflow circular slots located at the decanter centrifugation unit liquid compartment side of 25% closed.

This paper's main objective is to examine the feasibility of a specific pretreatment process, and hence, provide an initial platform for future development on a larger scale. The work involved erection and operating pilot-scale centrifugation unit to mechanically separate most of silt and sand from a seawater feed of SPDP station. The specific objective is to assess the viability of the decanter centrifuge unit using 25% closed mode for enhancing the quality of seawater feed at SPDP station.

2. Experimental setup

The process diagram for the decanter centrifugation system is depicted in Fig. 4. Turbid seawater was fed to the decanter centrifugation feed tank equipped with an agitator to prevent silt/sand precipitation, after passing through four clarifier tanks with a capacity of 1 m^3, each followed by a strainer. The aim of the clarifier tanks was to stabilize the quality of the feed and to increase the contact time for the coagulation and/or flocculation process. Acoagulant (ferric sulfate) and a cationic polymer as a coagulant aid were added to the turbid seawater after the submersible pump, followed by a static mixer and clarifier tanks. Coagulation is a process to make small particles into larger aggregates by neutralizing the electrical charges on the surface of the particles. Coagulants that are commonly used include alum, ferric salts, lime and polyelectrolyte [21].

One centrifugal pump is used to pump the turbid seawater feed from the feed tank to the decanter centrifugation system through a centrally arranged inlet tube, and is then distributed through several tube openings in the interior region of the decanter bowl (part 3 in Fig. 5(a)). The centrifugal force developing, while the decanter bowl is rotating, flings the solids onto the internal walls of the bowl where they form a sediment layer. The solids are delivered through a screw conveyer to the solids compartment and are then supplied through outlet openings (part 3 in (a) and (b) of Fig. 5) in the rotation unit and into the solids chamber in the housing of the decanter. The solids are then supplied through the drain funnel and the spiral conveyer (part 5 in Fig. 5(a)) in the under section of the decanter and into an outside tank that is positioned below the unit container. The treated seawater flows into the rear section of the rotation unit where it passes four overflow circular slots to the liquid chamber and directly to the product tank. The rotation unit has a cylindrical shape with a conical end. The cylindrical part features the drain for

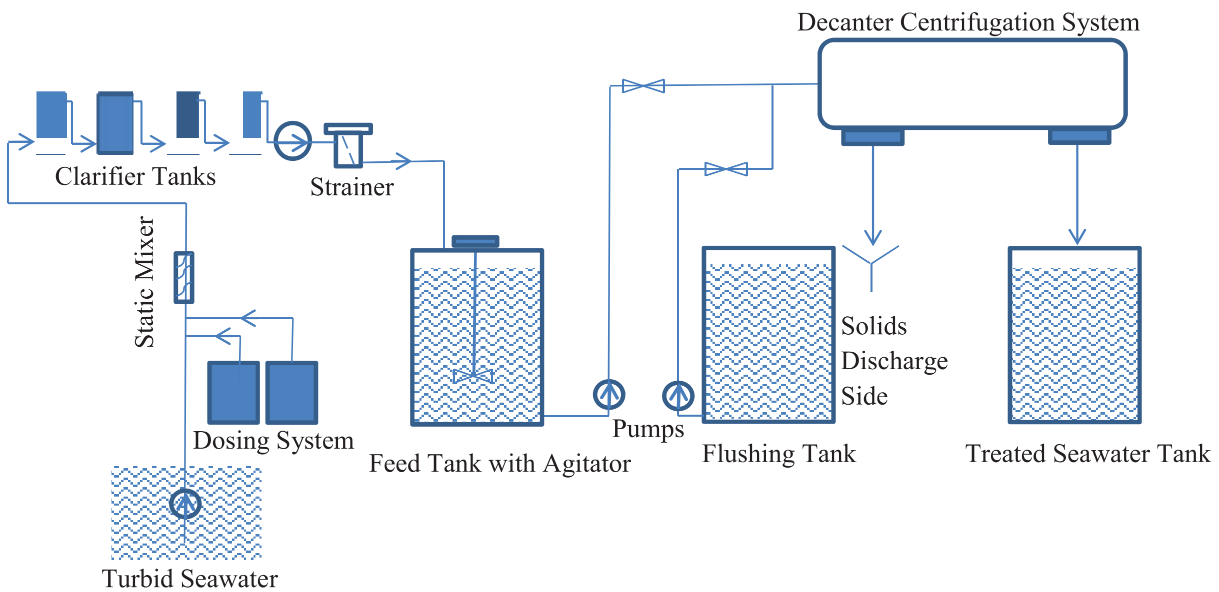
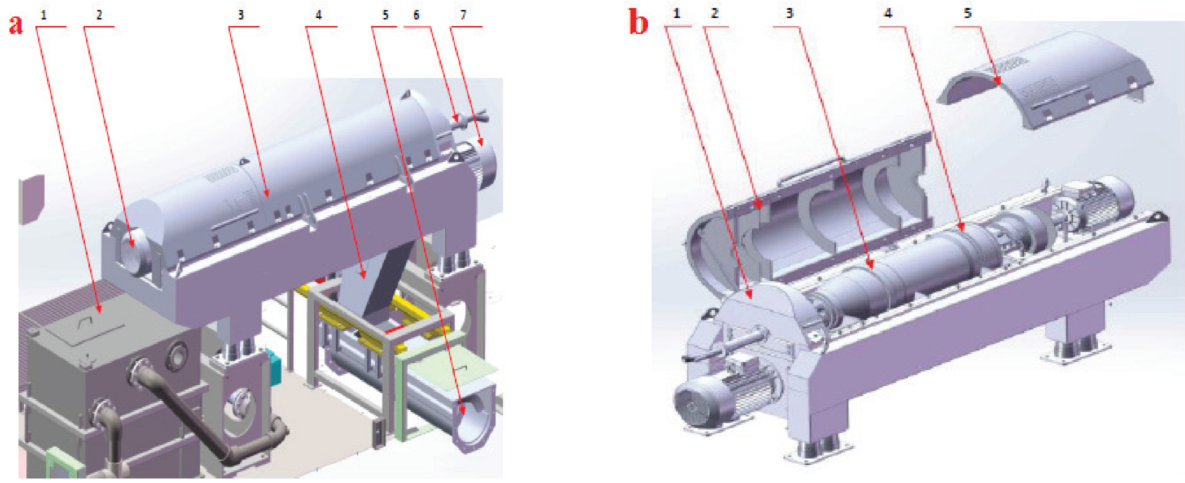


Fig. 4. Flow diagram of the decanter centrifugation unit.



a: 1. Product water tank ; 2. Screw drive motor; 3. Rotation unit (bowl, screw, etc.); 4. Solids chute/hopper; 5. Spiral conveyor; 6. Inlet tube; 7.Rotation unit drive motor.

b: 1. Cover belt drive; 2. Rotation unit house cover; 3. Solids chamber; 4. Liquid chamber; 5. Gear cover.

Fig. 5. Decanter centrifugation unit.

the treated seawater which is called the liquid compartment (part 4 in Fig. 5(b)). The conical part features ejection openings for discharging the solids/concentrated turbid seawater into the solid chamber of the housing, which is called solid compartment (part 3 in Fig. 5(b)). The circular slots in this study were 25% closed.

2.1. Instrumentation and experimental procedure

The decanter system used in this study has been purchased from ITE GmbH, Dresden, Germany. The decanter has been assembled by the following relevant modules: Centrifuge unit ZR14035 by Hakki Usta, Turkey consisting of: (i) Decanter centrifuge DDD3542, (ii) 5.5-kW screw drive motor, (iii) Cyclo drive centrifuge gear, which can transfer a torque of maximum of 12,000 NM, (iv) The rotation of the bowl drive motor has a power of 22 kW, while the screw drive motor has a power of 5.5 kW. The bowl drive can reach to a maximum speed of 2,950 rpm via a belt. The differential speed of the screw and the bowl is 50 rpm maximum, (v) Capacity up to 15 m^3/h, and for more technical specification, refer to Decanter model number ZR14035.

The experiment was performed using a decanter centrifuge unit with circular slots of 25% closed, bowl rotation speed of 2,500 rpm, the speed difference between a bowl and screw of 35 rpm, and seawater feed flow of about 3.5 m^3/h. The performance in this test was monitored for about 11 d of continuous operation. During a total actual testing time of 265 h of operation, the decanter unit was stopped only twice. The first time was for only 1 h and 10 min because of low tide; while the second time was only for 15 min to grease the decanter bowl motor bearings. Because of this, the actual testing period was longer than the actual running time, giving the decanter unit 99.6% of availability. In general, the decanter unit must be shut down to grease the screw, bowl and gearbox of the decanter centrifuge unit for periods of 15, 30 and 60 min each for 100, 200, and 2,500 running hours of operation, respectively. The total power consumption during the operation period reached 2,390 kWh; while the total chemical consumption was 0.03 and 0.045 m^3 for the ferric sulfate as a coagulant and the cationic polymer, respectively. During the time of operation, the 1-μm filter was changed only five times.

3. Results and discussion

Fig. 6 presents the turbidities of the feed, product before and after the filter (NTU), and reductions before and after the filter (%) vs. running time using 25% closed mode. The data for this test were usually taken on a daily basis between 8:00 am and 9:00 pm. Therefore, the consistent gaps found in Fig. 6 were only because of the times that no data were recorded between 9:00 pm and 8:00 am. The first thing that can be noted in this test was that there was no discharge in a liquid form coming from the solid side compartment. This clearly indicates that the decanter centrifuge using the 25% closed mode had treated 100% of the feed water.

Fig. 6 shows that the turbidity of the feed fluctuated between minimum and maximum turbidity values of 20 and 188 NTU, respectively; while the product fluctuated between minimum and maximum values of 5.275 and 91.45 NTU, respectively. In general, the product turbidity followed a similar trend as the turbidity of the feed, which means that as the turbidity of the feed increased the turbidity of the product increased and the opposite was true. Fig. 6 also shows that the unit was able to remove and/or reduce silt and sand from seawater by an average of 60%–65%. The fluctuation in the product reduction, which reached a maximum value of about 92% when the feed turbidity was in the range of 111 and 120 NTU; while it reached only about 82% when the feed turbidity was in the range of 188 NTU. This could be attributed to the fluctuation in the turbidity of the

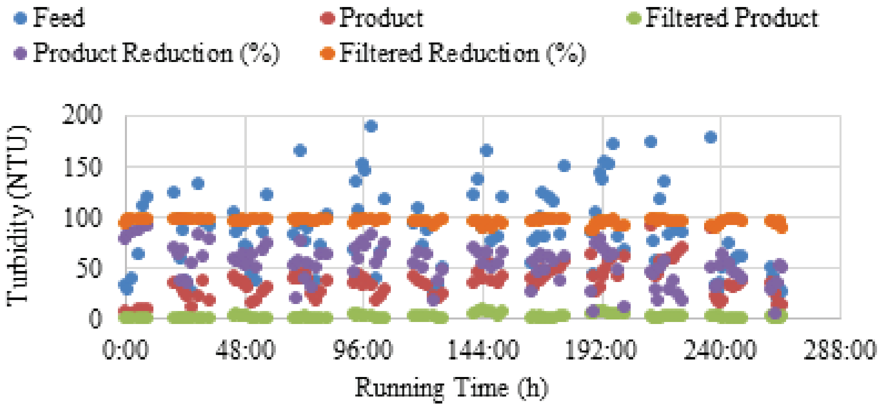


Fig. 6. Decanter centrifuge feed and product before and after filter turbidities (NTU) and reduction before and after filter (%) vs. running time.

Fig. 7. Fine dust coming out as a discharge from the solid side compartment.

feed in addition to variation in particle size at the time the measurements were taken. The turbidity values measured after the 1-µm filter was less than 3 NTU most of the time during the operation period, which made the final treated turbidity reach the range of 96%–98%. However, the turbidity values after the filter was also in the range of 4–8 NTU in few occasions, which made the final treated turbidity fluctuate between values of 87% and 95%. This could also be due to the variation in particle size at the time the measurements were taken.

Another issue that needs to be raised is the discharge issue. After about 4 d of starting this test, dusty fumes were noticed coming out of the solid side compartment and had increased in quantity as the operation continued. The fine dust could be observed actually everywhere, such as inside the solid spiral conveyer compartment, outside the container opposite the spiral conveyer compartment side, and over the instruments and tanks inside the unit container as seen in the images presented in Fig. 7. Fig. 8 presents a sample of the fine dust collected after the test period was completed. This clearly indicated that the silt and sand accumulating inside the decanter for some time would finally come out as dry powder and could be transferred and disposed away from the SPDP station.

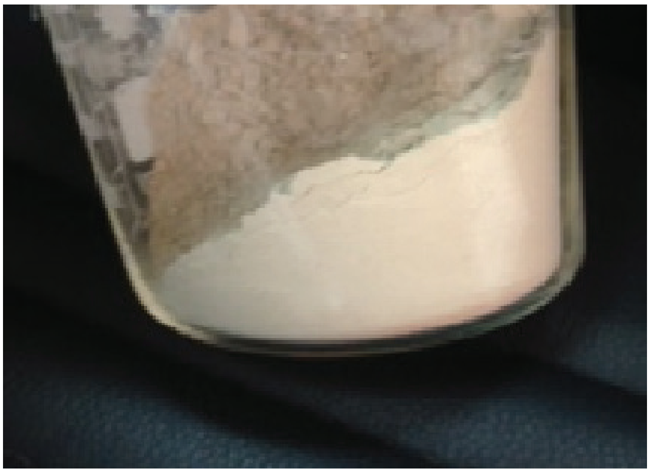


Fig. 8. A sample of the fine dust coming out from the solid side compartment.

Table 1
Power consumption for decanter centrifuge system

Mode	Flow (m^3/h)	Power Consumption (kW)	Power Consumption (kWh/m^3)
25%	3.1	10	3.20
Closed	6.8	10	1.47
	8.5	12	1.41

Power consumption of the aforementioned decanter unit test was calculated as presented in Table 1. Table 1 shows that the unit was operated for about 48 h, at a bowl speed of 2,500 rpm, bowl and screw speed difference of 35% and at different feed flows. Results showed that the power consumed were 10, 10 and 12 kW using flow of 3.1, 6.8 and 8.5 m^3/h giving total power consumption per cubic meter of 3.2, 1.47 and 1.41 kWh/m^3, respectively. This behavior showed that as the flow increased, the power consumption decreased, which gave a clear indication that the power consumption treating seawater, utilizing decanter centrifuge with a bigger capacity will be in an acceptable range.

4. Conclusions

In this study, the decanter centrifuge unit was tested under a bowl rotation speed of 2,500 rpm, the speed difference between a bowl and screw of 35 rpm, seawater feed flow of about 3.5 m^3/h, and the four overflow circular slots located at the decanter centrifugation unit liquid compartment side of 25% closed. Evaluating the decanter centrifuge using the aforementioned operating conditions and its effect in enhancing the seawater quality at SPDP revealed that the decanter is a viable mechanical process for improving the quality of the SPDP seawater feed. The system was able to treat 100% of seawater feed, with availability of 99.6%. The separated silt and sand by the decanter centrifuge unit is coming out as a fine dry powder from the solid side compartment, which can be collected and transferred out of the SPDP station. This clearly indicates that the silt and sand will not be accumulating in the unit causing frequent stoppages for flushing and cleaning. With regard to power consumption, the study showed that as flow increases, the power consumption decreases, which gives an indication that the power consumption treating seawater, utilizing decanter centrifuge with a bigger capacity will be in an acceptable range.

The experimental data obtained in this paper can provide important details that can be used as a reference for designing a bigger scale unit for further research and development. However, further study is required to examine different overflow circular slots located at the decanter centrifugation unit liquid compartment side such as fully open, 50% closed and 75% closed and other operating conditions. Detailed technical–economic analysis is recommended to be taken into consideration in future study and compare the figures obtained to other conventional solid and/or liquid separation technologies.

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