# Electrokinetic Flotation of Paint Solids in a Continuous Flow Tank

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*Introduction*

The treatment of water from paint spray booths in automobile assembly plants typically involves applications of large quantity of chemicals as coagulants and flocculants. Suspended paint solids are brought to water surface in sludge pits after these chemicals are added. The suspended paint particles are then mechanically collected and removed as sludge for further treatment and disposal. There are several disadvantages of the existing floatation process, including:

1. The cost of chemicals;
2. The dosage (feed rate) and type of chemicals need to be closely monitored and routinely tested to ensure the performance of the system. This increases the operation costs.
3. Unsatisfactory performance of the system may not be discovered and corrected immediately. This causes sludge build-up in the sludge pit and recirculation system, leading to additional maintenance costs.
4. Chemicals added to the sludge pit are non-recoverable and increase the mass and volume of the sludge generated in the process. This leads to higher disposal costs.

A study was carried out in an effort to explore alternative solutions for treating the circulating water in paint operation systems. Electrokinetic flotation (EKF hereafter) was tested for removing suspended paint solids from water. The EKF is based on principles of electrostatics and electrochemistry, including (1) directional movement of electrically charged particles in an electric field (electrophoresis and dielectrophoresis), (2) oxygen and hydrogen gas bubbles generated by an electric current through conducting electrodes (electrolysis) and (3) flocculation generated by changes of surface charges of suspended solids under the influence of the electric filed. As a result, when a DC field is applied via submerged electrodes in the circulating water with suspended paint solids, electrophoresis and dielectrophoresis generates movement of paint particles, the electrical field generates flocculation of paint solids to form larger flocs, and electrolysis generates gas bubbles at the both cathode and anode that carry paint particles and flocs to the water surface. The influencing parameters of EKF treatment include the water electrical conductivity (EC), electrode type and layout, type of paints, paint solid loading, and applied DC current. The results showed that the EKF process generated quick floatation of paint particles without using any flocculants. The suspended solids (SS) in the sludge water are significantly reduced along with significant color and COD removal. This paper presents the results of a study using a lab-scale continuous flow tank that simulates the paint spray operation in an automatic assembly plant.

*Background*

Flotation is commonly used in water and wastewater treatment and is most effective for the separation of low-density suspended solids and oil *(Lafrance et al., 1995; Chen & Horan, 1998; Huang & Liu, 1999; Vaughan et al., 2000; Manjunath et al., 2000)*. The first attempt to use electrokenetic flotation (also known as electroflotation) was by Elmore *(1904)* who used the technique to separate minerals from ore. EKF has been an attractive alternative because of characteristics such as high separating efficiency with shortened process duration, simple operation, small and compact equipment, and requiring few accessories. The EKF method has shown to be effective in removing suspended solids, oil and grease, organic pollutants, as well as sludge from wastewater. Experiments have shown that smaller gas bubbles are more efficient in the flotation of fine particles *(Bennett et al., 1958; Ahmed & Jameson, 1985; Ketkar et al., 1991; Burns et al., 1997)*. EKF generates essentially uniform and fine gas bubbles. The gas bubble flux can be adjusted by varying the current density on electrodes. The performance of an EKF system for treating oily wastewater has been proven to be better than either dissolved air flotation, sedimentation, or impeller flotation (IF) *(Il'in & Sedashova, 1999; Chen, 2004).*

A major challenge in EKF treatment is the electrode system design. The common electrode materials for EKF include iron, aluminum, stainless steel and coated titanium anode ($Ti/IrO_x$). The former three materials are cheap, readily available, but are consumable during an EKF process. The $Ti/IrO_x$ anode represents the state of the art anode development, which is non-consumable and stable.

*Continuous Flow Tank for EKF Study*

The design of the lab-scale continuous flow tank is based on the paint spray operation in an automobile assembly plant (Fig.1). The water circulates between the paint spray booth and sludge pit. In the spray booth, the paint over- spray is forced into the underlying circulating channel by drawn-down air. The circulating water carries the paint solids to the sludge pit, where they are separated from water by chemical floatation.

The continuous flow tank has geometrical dimensions proportional to those in the plant, and all tests performed in the tank are designed based on the similar hydraulic retention time (HRT) (6-8 minutes). The facility consists of a treatment tank (simulating the sludge pit in the plant) and a mixing tank. The water used in the experiments was prepared from a concentrate ($Q_1$), which was fed to the treatment tank ($Q_3$) and returned to the mixing tank ($Q_2$), as shown in Fig. 2. The recirculation pump keeps water circulating between the mixing tank and the treatment tank, and the feeding pump controls the paint solid loading in the treatment tank by adjusting the feeding rate of the concentrated paint sludge water.

The electrode designed for the continuous flow EKF tests is made of fine grain (0.0004”) graphite. The electrode module consists of 13 graphite plates, 70 mm in width, 15 mm in height and 6 mm in thickness, as shown in Fig. 3(a). The face-to-face spacing of the graphite plates is 18.5 mm. The electrode placement in the treatment tank is shown in Fig. 3(b). The module can be removed from the tank without shutdown water circulation. The position of the electrode module in the tank is adjustable for optimum treatment effects. The water-borne base coat sludge water was prepared by spraying the paint with 80 kPa air pressure into a bucket containing tap water. The TS concentration was measured and adjusted based on the design target.

*Results*

Two types of EKF tests were carried out in the continuous flow tank, i.e. the close-loop test and open-loop test.

The close-loop test was performed with a constant initial suspended solid (SS) concentration. There was no additional paint solid loading during the close-loop EKF process. As a result, the SS of the paint sludge water reduced with time and reached the minimum. Figure 4 shows the results of a close loop test, presented as the SS versus treatment time. The Figure shows SS removal by EKF and chemical coagulant is comparable and much higher than the control test under the same initial SS concentration.

The open-loop EKF tests were designed to simulate the operation of paint spray booth and sludge water treatment and circulation. As shown in Fig. 2, the concentrate is fed to the mixing tank using a variable-speed tubing pump, where it is mixed with circulating water. The SS concentration of the mixed water simulates the water coming from the paint spray booth. The mixed water flows into the treatment tank to undergo EKF treatment. The treated water (the circulating water) is pumped back to complete the loop. The open-loop EKF tests included a control test, a chemical coagulant floatation test and an EKF test. A water-borne paint was used to prepare the concentrate. Three tests were carried out under the same SS loading rate and hydraulic retention time (HRT). The initial SS concentration of the water was zero (tap water). The SS of water increased with time to simulate the operation of the paint spray booth. The coagulant dosage rate was 0.21 mg/L/min in the chemical floatation test, and the applied DC current was 0.5 A in the EKF test. Fig. 5 shows the SS concentration vs. treatment time in the open-loop tests. In the control test, the SS concentration increased with time to 170 mg/L after 28 hours. In the coagulant and EKF test, on the other hand, the SS concentrations remained below 20 mg/L during the entire testing period of 48 hours. It is also noticed that the SS concentrations reached equilibrium after 32 hours in both tests.

The mass balance of the paint sludge after the chemical and EKF tests was analyzed and shown in Fig. 6. The results indicate that in the EKF test, 61.4 % of the suspended paint solids became the floated sludge, on the other hand, in the coagulant test, only 1.9 % of the total paint solids sprayed floated to the top of the sludge tank. It was also noted that the EKF test generated much less sediment than the coagulant test. The result indicated that floatation in the EKF process is generated by hydrolysis induced gases whereas coagulant floatation relies on air bubbles from flow turbulence. The flow in the lab continuous flow tank is laminar with low a Reynolds number, which explains the negligible floatation in the coagulant test.

Figure 7 presents the water quality during the EKF test. It is noted that water quality remained stable during EKF testing. It is also found that water temperature change was not significant (Fig. 7(b)), indicating the EKF test did not generate significant heating effect under the lab-scale conditions.

*Summary and Conclusions*

The results of the laboratory continuous flow tests on EKF have shown the benefits of EKF treatment of paint sludge water, including

1) EKF generated significantly better paint sludge flotation than that by the chemical coagulant;
2) The EKF process eliminated coagulant and other chemicals, which lead to less sludge;
3) The water quality in the EKF treatment is comparable to chemical coagulant treatment;
4) The EKF requires DC current and the power consumption depends on the water electrical conductivity
5) Heating in EKF treatment is insignificant (< 5°C)
6) Water remained neutral water pH during the EKF operation

The EKF technology has other features such as COD removal, simple implementation, retrofitting to existing sludge treatment systems, easy operation and control, as well as no adverse environmental impacts.

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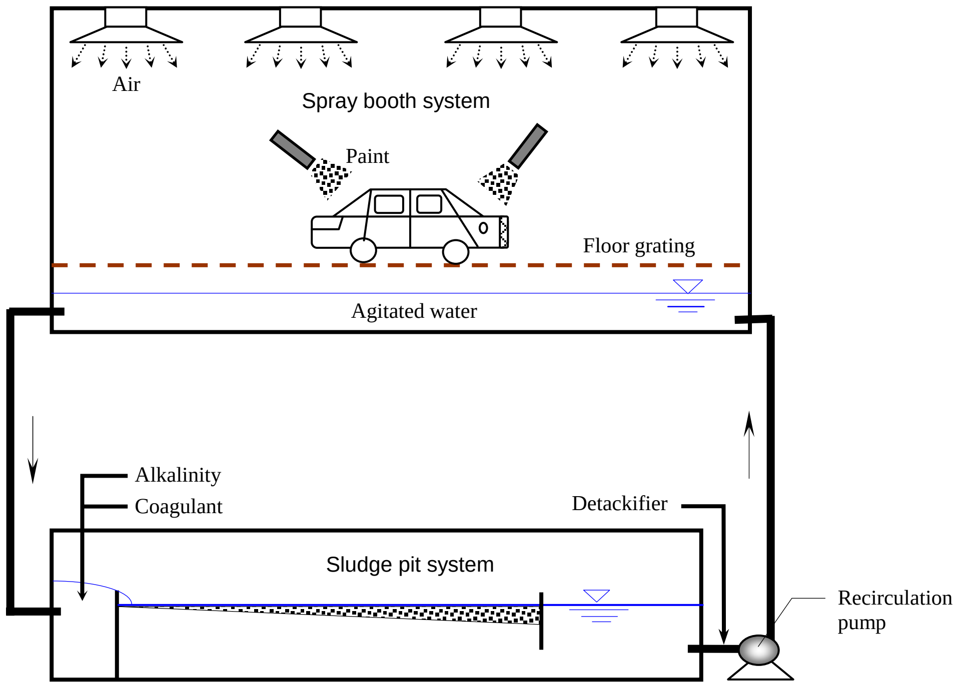
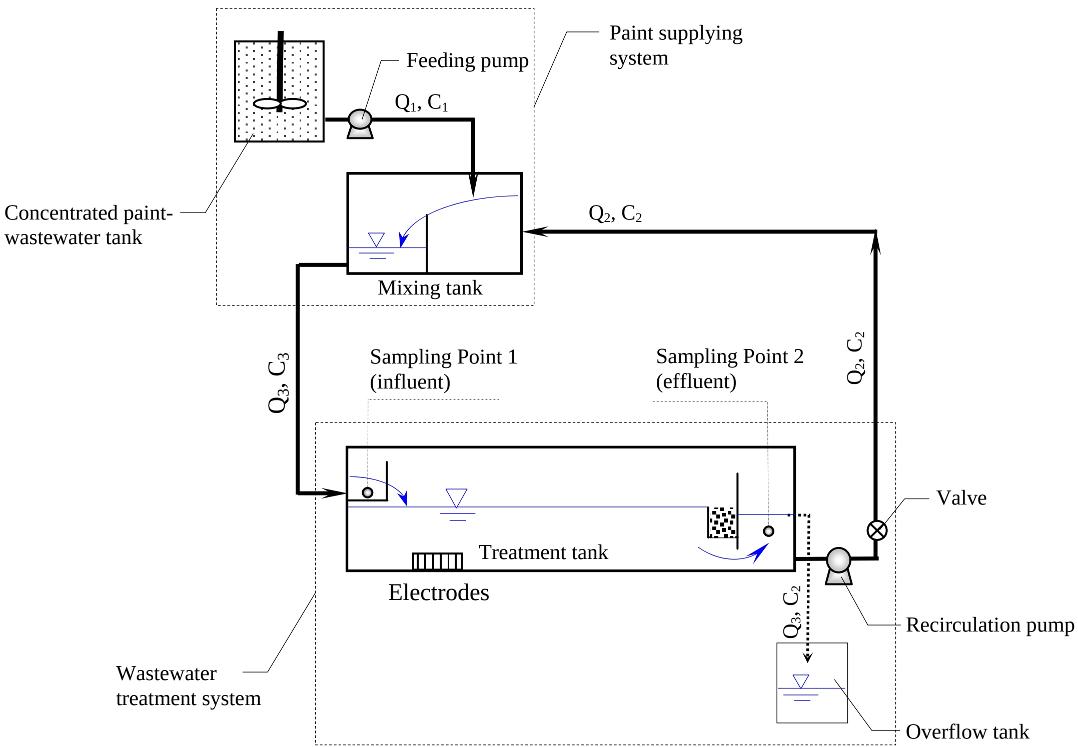


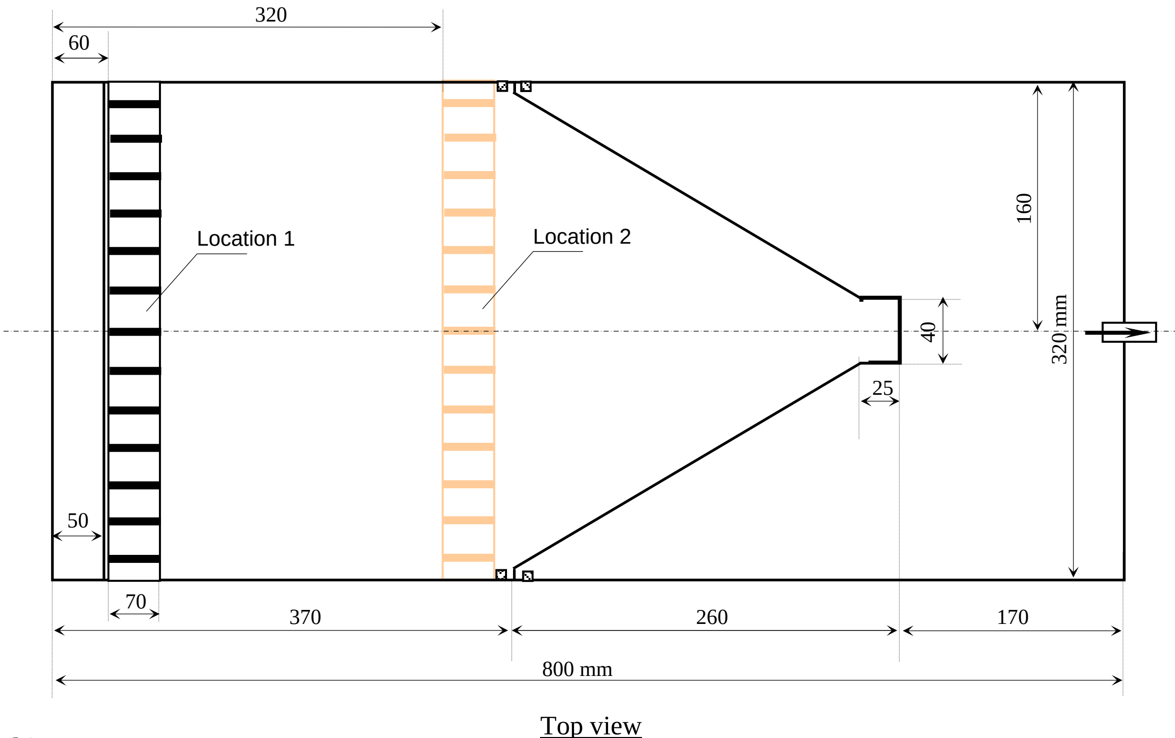

Fig. 1 Schematic of the paint spray booth and sludge pit in an automobile assembly plant.




- Effective volume of treatment tank: 38.4 L;
- Capacity of recirculation pump: 0 to 14 L/min;
- Capacity of feeding pump: 0 to 67.5 mL/min
- Minimum Hydraulic retention time of treatment tank: 2.7 min;

Fig. 2 Schematic of the lab-scale continuous flow system

(a)




(b)

Fig. 3 Electrodes in the continuous flow tank, (a) electrode; (b) electrode location in the tank.

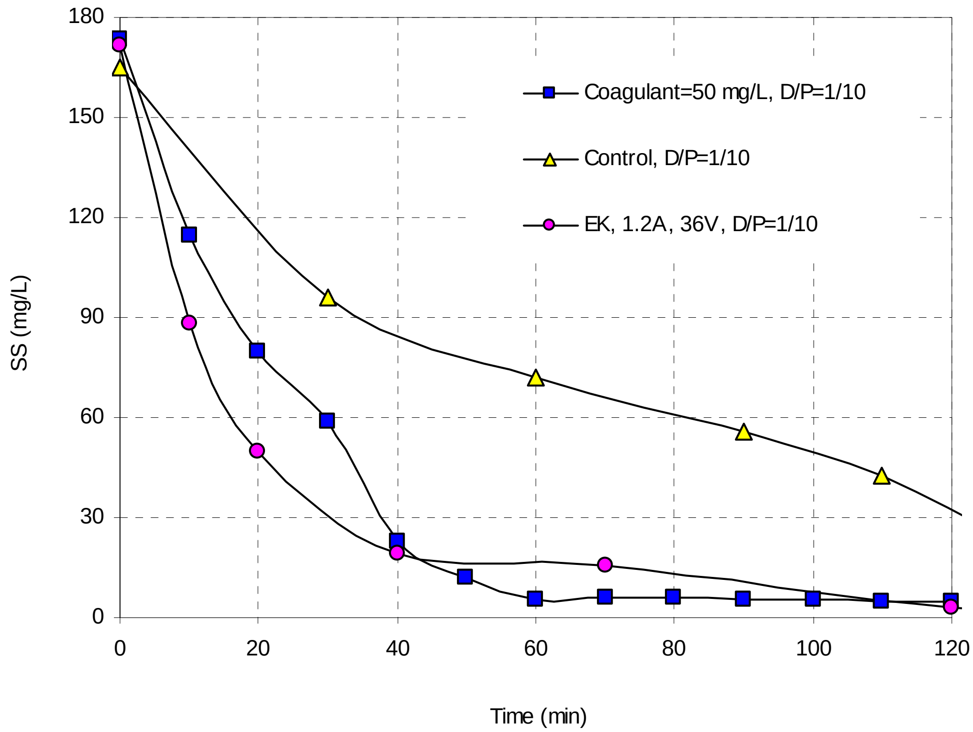



Fig. 4 Close-loop EKF test: SS concentration versus time in control, EKF and coagulation tests

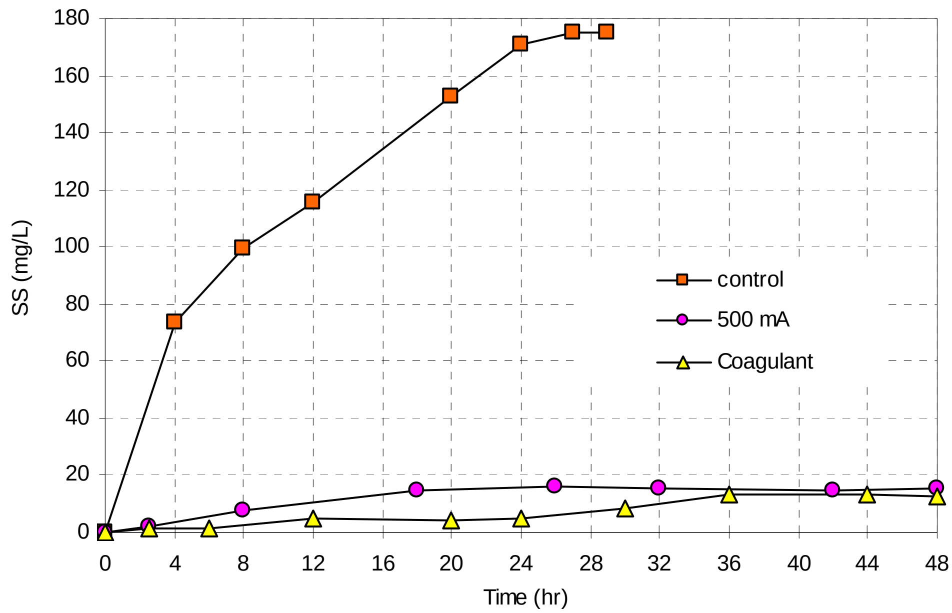



Fig. 5 Open-loop EKF test: SS concentration in control, EKF and coagulation tests

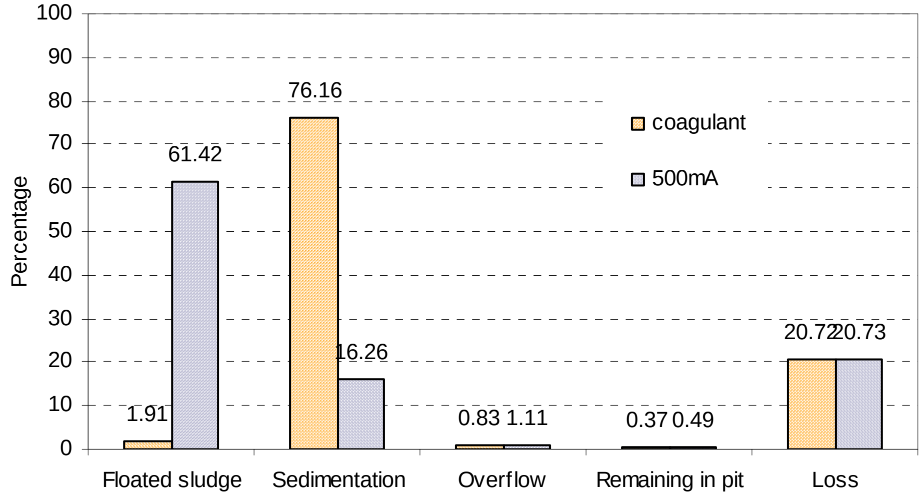



Fig. 6 Sludge mass balance after the open-loop test.

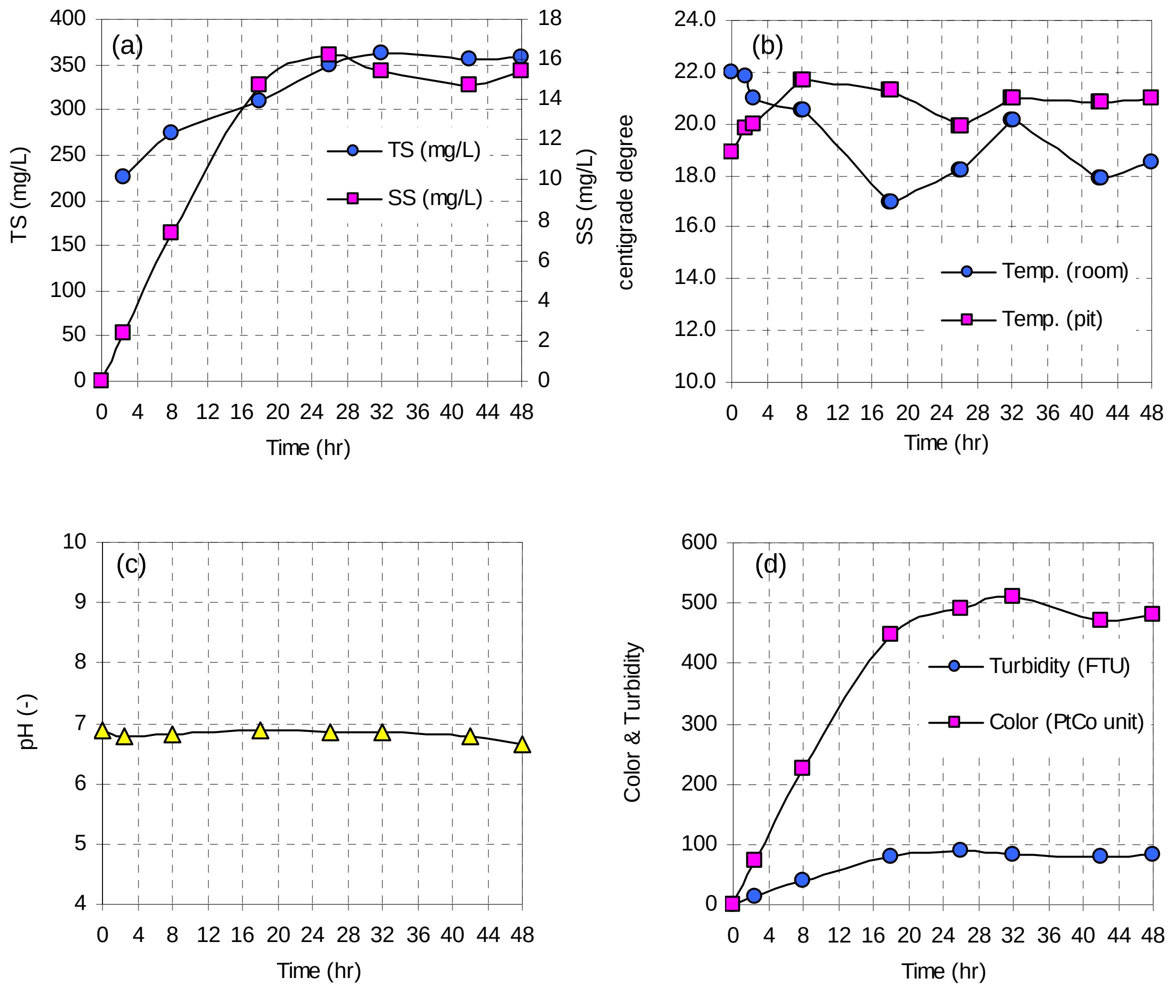



Fig. 7 Results of the open-loop EKF tests: (a) TS and SS; (b) temperature; (c) pH, (d) Color and turbidity.