EFFECT OF AERATION ON DISSOLVED OXYGEN PROFILE AND HYDRATION DURING COLD SOAKING IN PADDY PARBOILING PROCESS

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Abstract

Rice production is a key component in the Sri Lankan economy. Paddy is processed to produce raw or parboiled rice. In parboiling process, cold soaking uses about 1,300 liters of water per tonne of paddy. About 70% of the water used in parboiling with biochemical oxygen demand (BOD) ranging from 950 to 1300 mg/L is discharged as effluent into the surface waters, causing environmental damage. Anaerobic condition in the cold soaking process is considered the primary reason for high BOD of the effluent. Maintaining aerobic conditions would reduce the effluent strength. Study of dissolved oxygen (DO) profile, in the soaking water, is important in the design of an aerobic cold soaking system.

An experiment was conducted to study the DO profile in conventional and aerated soaking processes using 12 month old small grain paddy. Soaking tests were 48 hour duration and DO concentration was measured intermittently. When DO reduced to about 1.0 mg/L, water was aerated by circulation through a shower, Aeration was stopped when increased to about 8 mg/L. This cycle was repeated for 48 hours. Moisture content of paddy, chemical oxygen demand (COD), and pH of effluent were measured during the experiment.

Initially, it took about 9 hours of soaking for DO to deplete to lower limit and aeration to upper limit took only 25 minutes. As the experiment progressed time for DO depletion decreased and time for aeration increased. After about 21 hours, the depletion-aeration cycle stabilized at about 3 hour total cycle time. The moisture content (wet basis), COD and pH of effluent were 36.4%, 238 mg/L, and 6.83 respectively after 36 hours of soaking.

Key words: Dissolved oxygen, Submerged aeration, Cold water, Paddy Soaking, Parboiling

1. Introduction

Rice occupies the third place in terms of global grain production, 461 million tonnes leaving corn (868 t) and wheat (689 t) in the first and second places (USDA, 2011). Rice is the single most important crop occupying 34 percent of the total cultivated area in Sri Lanka (Department of Agriculture, 2011) with a total production of 3.7 million tonnes in the year 2011 (Department of senses and statistics, 2011). Paddy grains are processed into rice either as raw or parboiled rice forms. Most of the people in Sri Lanka consume rice as their staple food and 70% of rice is consumed as parboiled rice (Palipane, 1988). Further, rice is very important as it is the staple food grain with a per capita annual consumption of 114kg and the livelihood of 1.8 million farm families in the country (Department of Agriculture, 2011). There are about 7000 rice mills available throughout the country of which 77% are custom mills and rest is commercial mills for processing paddy with a capacity of 2700 tonnes per hour (Palipane, 1988; Senanayaka *et al*, 2005). Parboiled rice is becoming popular in the country as well as in the world due to its lower Glycemic Index (GI) value than its raw form (Glycemic Index, 2012). Therefore, the parboiled rice industry is of prime importance as it plays a key role in the Sri Lankan food industry.

Rice Parboiling has three main steps namely, soaking, steaming and drying. Soaking process consumes considerable amount of water for processing and it is about 1.3 times of the weight of paddy (Wimberly, 1983). A minor fraction is absorbed by grains to increase the moisture content from 14%-30%, whereas, the rest of the water is left as an effluent with higher BOD values (1350-1800ppm) (Senanayake, 2001; Prabodhani, 2009). Most of the rice millers in Sri Lanka discharge rice mill effluent directly to the environment without treatment, which is illegal according to the country's environmental law. The effluent treatment is usually expensive and small and medium-scale rice processors cannot afford it. Various microbes are functioning under anaerobic conditions during the conventional soaking process and this anaerobic situation may develop off flavor in rice grains. Microbial load will increase in both water used for soaking and in paddy grains with soaking time (Ramalingam, 1996). Further, Dissolved Oxygen (DO) and BOD are strongly associated with each other. Reduction of the concentration of DO will indicate the increment in BOD and COD of the effluent. Depletion of DO is common in the soaking process due to microbial activities and proliferation (Ramalingam, 1996). Natural circulation of water, under submerged conditions, will keep high DO level in water to prevent the development of anaerobic conditions. Study of dissolved oxygen profile in the soaking water is thus vital to optimize soaking process in terms of oxygen saturation concept. Soaking paddy by continuous sprinkling and circulation of water has been reported by Senanayake (2001) and Prabodhani, (2009). However, the DO profile which is the key principle has not yet been studied or reported so far. Continuous circulation and soaking will consume relatively high energy for pumping than submerged soaking; further increase the cost of production. Therefore, the objective of this study was to study the potential of aerated soaking by maintaining a positive DO level in soaking water under submerged condition and compare it with conventional soaking process. The hypothesis of this study was that the maintenance of aerobic conditions would reduce the effluent strength. Study of dissolved oxygen (DO) profile in soaking water is thus important in the design of an aerobic cold soaking system.

2. Materials and Method

A PVC pipe of 1.5m height and 100mm in diameter was used as the testing tank as shown in the figure1. The height was selected based on the height of the commercial level soaking tanks. One end of the pipe was sealed with an end cap and used as the soaking container. This test rig was sufficient for soaking 4kg of small grain paddy with 5L of water, allowing 4cm standing water level above the grain surface for providing a submerged condition. The water level was kept 150mm below the top of the pipe edge for convenient operation. A 50mm PVC pipe was used for water circulation and aeration unit as shown in the figure 1. A DC 12V centrifugal water circulation pump with a flow rate of 1 L/min, was fixed in line and powered by a 12V, 90 ampere hours battery. A showerhead, having fine holes of the diameter less than 1mm, was used to sprinkle water on to the soaking paddy column while aerating the soaking water. Shower was kept 0.6m above the top of the paddy soaking PVC pipe. The experimental setup is shown below (Fig. 1 & 2). A Similar PVC soaking column was made for traditional cold water conventional soaking which was used as the control of the experiment.

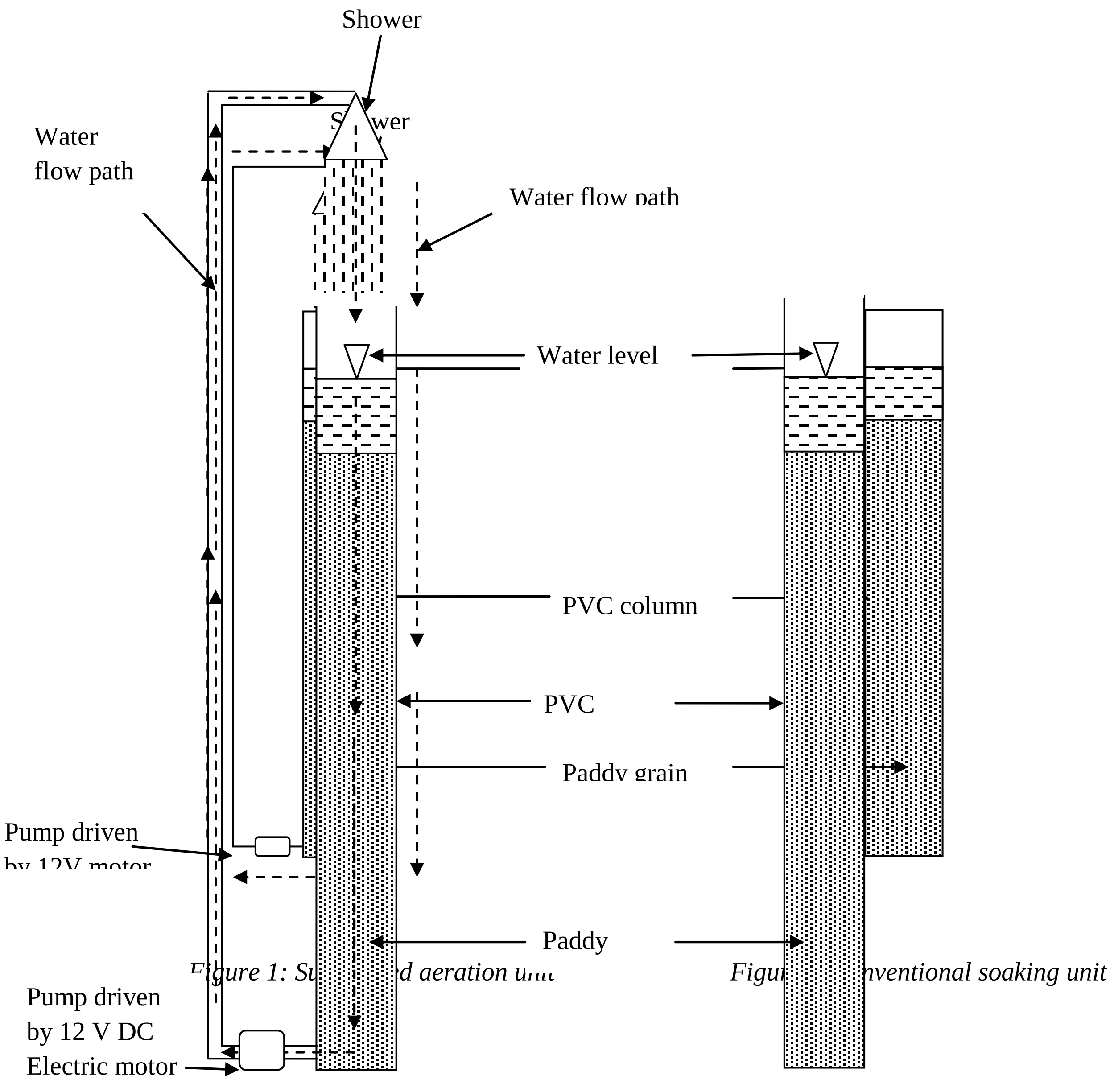

Figure 1: Su[illegible]d aeration unit

Figu[illegible]nventional soaking unit

2.1 Measurement of Dissolved Oxygen

A portable DO oxygen meter (Model: DO 550a, Analytical Grade) was used for the measurement of DO content of the soaking water and the meter was precalibrated in air to the value 20.9 to make accurate DO measurements. DO was measured at hourly intervals until a predetermined minimum value was reached. The water aeration was started when the DO level in soaking water reached the 1 mg/L predetermined value. Under room temperature, the oxygen saturation level of water was around 8- 8.2 mg/L. Circulation pump was operated until DO concentration reached the saturation level and the pump operating times were recorded. The DO concentration was measured continuously to check the depletion pattern. Pump was operated whenever the minimum DO concentration was reached in soaking water.

2.2 Determination of Moisture Content

Moisture content was measured by the oven dry method. Three 100g paddy samples were drawn and kept in a convection oven at 130^{o}C, for 24 hours. Final and initial weights were measured using a four decimal electronic balance and the moisture content was calculated using the following formula (IRRI, 2009).

$$Moisture\ content\ (wb) \quad = \quad \frac{Initial\ \ weight - Final\ \ weight}{Initial\ \ weight}\ x\,100\ \ \%$$

The determination of moisture content and study of the grain hydration levels were carried out to study the minimum soaking time required for grain moisture saturation of ≥30% for energy efficient steaming.

2.3 Determination of Biochemical Oxygen Demand (BOD) of soaking water

The DO content of liquid was determined by Winkler's titration method. DO concentration was measured at the beginning and after five days. The difference was recorded and correlated to BOD_5. Samples were diluted 100 times to increase the accuracy of the titration. For optimum biochemical oxidation, the pH of the samples for analysis was 6.5 to 8 (APHA, 1992).

2.4 Chemical Oxygen Demand (COD) Using the Open Reflux Method

The sample, to be measured, was oxidized under reflux with a known amount of potassium dichromate in strong sulphuric acid with silver sulphate as a catalyst. Organic matter reduced part of the dichromate and the remainder was determined by titration with iron (II) ammonium sulphate or iron (II) sulphate using ferroin as an indicator. Interferences from chloride were suppressed by the addition of mercuric sulphate to the reaction mixture. The chemical oxygen demand (COD) was expressed as milligrams of oxygen absorbed from standard dichromate per litre of sample (APHA, 1992).

3. Results and discussion

The dissolved Oxygen (DO) concentration is the key factor in the new submerged soaking process as it indicates the potential of anaerobic microbial activity leading to unpleasant odour. Anaerobic microbial activity is further influenced by the environmental temperature. The DO saturation in water under different environmental conditions was found from data tables. When the DO concentration is high in water, proliferation of aerobic microbes is well facilitated during their active phase and there will not be any anaerobic microbial growth. Although, the facultative microbes can survive, none of the microbes utilize sulphur compounds as their source of oxygen, releasing unpleasant H_2S odour. Water circulation by sprinkling water through a shower having fine holes under submerged condition has therefore been developed to keep DO concentration always at a positive level. It is used to make fine water droplets with larger surface area to saturate oxygen from the surrounding air by diffusion or atmospheric exchange. The shower head was kept at 2 feet above the top of the pipe in order to provide sufficient space and time to make the exchange process effective. As paddy grains have 50% porosity, recirculation of water is possible through inter granular spaces although there could be a slight pressure loss in the pumping process. A piece of a fine plastic mesh was placed as a strainer at the bottom of the soaking column to prevent the entry of paddy grains in to the circulation pump.

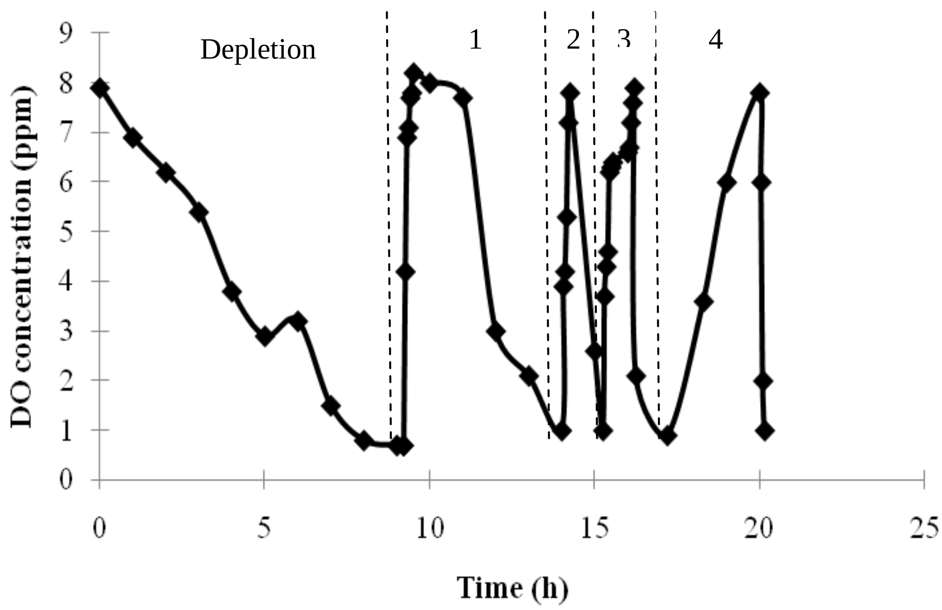

Figure 3: DO profile of different cycles of aeration after initial depletion during paddy soaking (1,2,3 and 4 – Saturation - Depletion cycles)

According to the figure 3, the DO level of initial soaking phase takes nearly 9 hours to drop to the lower limit and during the next five hours at the average ambient air temperature of 28±2, aeration was needed only once. However, oxygen depletion rate increased after that and aeration increased up to twice within next four hours as shown in the figure 3. Further, there are four saturation–depletion cycles illustrated in the above figure and saturation is due to circulation of water and depletion is due to aerobic activity of microbes. Thirty minutes (30 mins) of aeration is sufficient for the cycle 1 of the water circulation to reach the saturation level of 8.2 mg/L. This circulation, to reach saturation, is enough for another four hours to reach the minimum DO level, 1ppm. A DO level of 7.8 ppm is achieved after 30 minutes of aeration in the second saturation–depletion cycle and it took another one hour for depletion. Approximately three hours is needed to reach a DO level of 7.8ppm based on third saturation–Depletion cycle. Therefore, saturation was delayed. But, depletion is very rapid as indicated in the figure because of the continuous development of the aerobic colonies in both paddy grains and effluent. As of fourth saturation–depletion cycle, a DO value of 7.8 mg/L was reached after about three hours of aeration. But, it was depleted to the lower limit within 15 minutes. Cycle is stabilized after 21 hours of soaking.

The reason for high demand of oxygen is the increased microbial proliferation and activity on leached nutrients into soaking water from paddy grains. This is clearly indicated by the final air saturation time. Since the depletion rate was high, it took almost three hours to saturate oxygen. Further, the rapid depletion rate is indicated by the highest slope of the graph.

The DO depletion was also recorded for the control, the conventional soaking unit that had no aeration. The initial phase is same as the submerged aeration curve and after 15h time soaking water stayed as anaerobic. It in turn made the system anaerobic with high BOD values. Aerobic and anaerobic microbes get into the soaking water from paddy grains. The activity of microorganisms increases with soaking time. Aerobic microorganisms consume oxygen for their growth and proliferation from water but oxygen is a limiting factor for such organisms with time and the activity of aerobic organisms start to decline and anaerobic organisms become active and produce gases like, H_2S, CH_4 and CO_2. This process makes DO concentration low due the low atmospheric exchange into water in a 1.5m deep soaking column. It is clear from the graph that saturation is delayed and depletion is fastened as soaking time goes up. This is basically due to microbial population dynamics in both paddy grains and water used for soaking. Microbial population is increased in both paddy and effluent as soaking time goes up and the type of colonies is dependent on existing situation as either aerobic or anaerobic (Ramalingam, 1996)

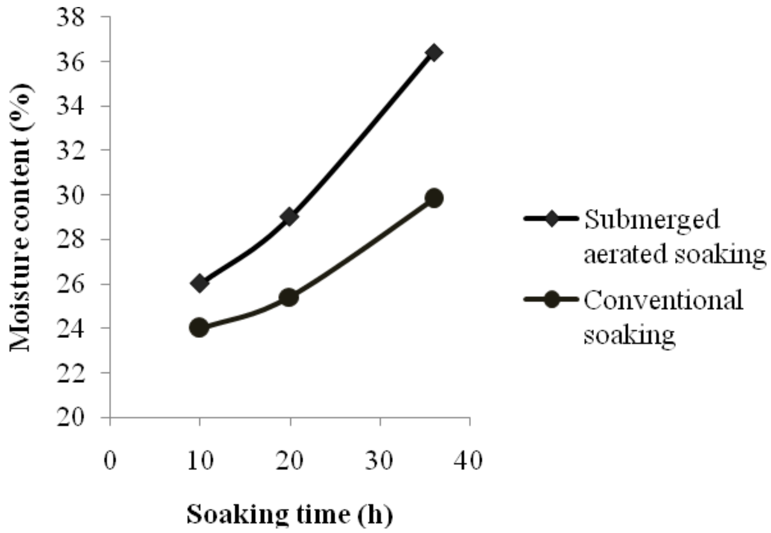

Figure 4: Hydration of paddy under conventional and submerged aeration

Figure 4 illustrates the difference of paddy hydration between the treatment and the control. Moisture absorption is basically dependent on existing moisture gradient, environmental factors and grain properties (Abhay *et al*, 2005). There are different sorption models developed for predicting moisture absorption patterns. Usually the first phase of moisture absorption rate is higher than second phase as the first phase is having a good moisture gradient, which declines with soaking time (Abhay *et al*, 2005). As the moisture content of the grain goes up, absorption rate reduces due to the reduction of moisture gradient. This determination was done to check the final moisture content of grain samples with standard values to optimize the process of submerged aerated soaking. Moisture contents of 29.8% and 36.4% have been obtained for conventional soaking and submerged aerated soaking, respectively for the same paddy grains after 36 hours of soaking (Table 1).

Table 1: Moisture content, pH and COD values of submerged aeration and conventional soaking

Soaking method / **Parameter**	**Submerged aeration**	**Conventional submerged soaking**
Moisture content (%)	36.4	29.8
pH	6.8	5.9
COD (ppm)	238	3540 (Senanayake, 2001)

There are different methods available for soaking of paddy for parboiling. Cold water soaking and hot water soaking are the most common methods practiced by most of the commercial processors. However, scientific investigations have been made to study the effectiveness of vacuum soaking and exposed aerated soaking in terms of moisture absorption rate, BOD and quality characteristics of milled rice. Cold water soaking is practiced by almost all small-scale processors, whereas hot water soaking is practiced by some commercial millers. Discharge of effluent with higher BOD values is a main environmental concern nowadays. Leaching rate of hot water soaking is 1.5 times higher than cold water soaking and it is not economical as it consumes significant amount of heat energy as well. Cold water soaking consumes high amount of water and takes longer time (48-72h) than hot water soaking to reach the moisture content of above 30%. According to the results, submerged aeration is effective in reducing effluent strength and also it needs an average soaking time of 21 hours to reach the moisture content of 30% for one year old paddy, which may minimize the leaching loss as well due to relatively short exposure time.

4. Conclusion

Results revealed that 9 hours of soaking for DO to deplete to a minimum limit and aeration to upper limit took only 25 minutes initially. Time for DO depletion decreased and time for aeration increased as the soaking time progressed. After about 21 hours, the saturation-depletion cycle stabilized at about 3 hour total cycle time. The moisture content (wet basis), COD and pH of effluent were 36.4%, 238 mg/L, and 6.83, respectively after 36 hours of soaking. It is therefore concluded that submerged aeration of paddy soaking is very useful in the parboiling process to reach desired moisture content with low strength effluent in terms of COD.

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