NUTRIENT AND SAND REMOVAL TECHNOLOGIES UTILIZED IN DAIRY MANURE SOLIDS SEPARATION

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INTRODUCTION

Mississippi presently has about 485 dairies with an average herd size of about 110 milking cows. Cow numbers have declined from four to eight percent in Mississippi for each of the past 10 years. This decline is typical of the southeastern United States, as southeastern dairy numbers have declined by 22 percent since 1992. While the number of southeastern dairies has declined by 22 percent, production is only down by seven percent, indicating increased herd sizes at remaining dairies (Moore 1997). These reductions are a result of reduced quality and quantity of labor in general. In addition, many second generation dairymen are opting for employment outside of the family farm.

In light of this, remaining Mississippi dairies will continue to increase in cow numbers. This has the potential to create many new problems for Mississippi dairymen. As cow numbers increase, an additional emphasis must be placed on animal health. However, increased cow numbers will also place additional load on existing waste treatment facilities. Therefore, remaining dairies will likely need expanded waste treatment capabilities. Many Mississippi dairymen utilize sand as a bedding material which can create additional problems in the waste treatment system. Efficient strategies for handling dairy waste in an economic and environmentally responsible manner must be developed for Mississippi dairymen to be competitive in the future.

Since many dairy producers already utilize a lagoon waste treatment system, the land application of lagoon wastewater via irrigation has become increasingly popular. A limitation of using irrigation for land application of dairy lagoon wastewater is the need for specialized equipment to handle the bulk solids (bedding, feed, etc.) associated with dairy waste. This has prompted the development of various manure solid separators which remove most of the bulk solids from the waste-stream. Removal of the larger solids can help reduce plugging in pumps, piping, and sprinkler nozzles (Fulhage et al. 1993). This can be beneficial, particularly if lagoon wastewater is applied with conventional "clean-water" irrigation equipment.

Manure solid separators have been in use for many years, but the advent of more rigorous environmental regulations has increased their popularity in the southeastern United States. Some of the more commonly used types are the static inclined screen, vibrating screen, rotary screen, belt press, perforated roll press, screw press, and centrifuge (Fulhage et al. 1993; Overcash et al. 1983). When these systems are employed, bulk solids are removed by mechanical methods and the remaining waste-stream continues on to secondary treatment.

While the removal of manure solids can improve the ability to land apply wastewater using irrigation methods, the dairy producer must now handle two separate waste-streams, liquid and solid. This situation has agronomic, economic, and environmental implications to the dairy producer. This has prompted a research study by the Mississippi Agricultural and Forestry Experiment Station (MAFES) to explore the benefits, if any, associated with solids separation on dairy waste-streams. To achieve this research goal, a manure solids separation research facility was designed and constructed at the Bearden Dairy Research Center in Sessums, Mississippi. The manure solids separation facility (MSSF) consists of a mechanical screen separator (MSS), a gravitational settling basin (GSB), and a concrete storage pad. The MSSF was designed such that the wastestream could be routed serially through the MSS and GSB or through the GSB only. Effluent exiting the MSSF proceeds to the anaerobic first stage lagoon (part of a three-stage lagoon treatment system) for additional treatment. This paper discusses measurement procedures as well as solids and nutrient removal efficiencies for the first year of operation.

BACKGROUND

The Bearden Dairy Research Center

The DRC features a gutter flush system for removing manure from the holding pens and freestalls. The DRC features a three-stage lagoon system. The primary (1^{st} stage) was designed to provide anaerobic digestion with stages two and three designed to provide aerobic treatment. A recirculation pump is installed in the third lagoon with the ability to refill all flush tanks in the system (flush tanks can also be refilled with clean water). Presently about 165 cows are being milked at the DRC. This includes approximately 125 Holstein and 40 Jersey cows.

The DRC uses sand for bedding in the freestall barn. Since sand is inorganic, it does not provide a suitable substrate for microbial growth. Sand provides a good cushion, thus enhancing stall use and cow cleanliness. Sand bedding also helps reduce mastitis risk, while maintaining foot and leg health. While sand bedding has many advantages for cow comfort and health, it can greatly complicate the manure handling system (Stowell et al. 1995). From an engineering perspective, sand deposited in the treatment lagoon poses a serious threat to the long-term operation of the lagoon treatment system.

Manure Solids Separation Facility (MSSF)

The manure solids separation facility, shown in Figure 1, incorporates two manure solids removal technologies, a mechanical screen separator (MSS) and a gravitational settling basin (GSB). Separated solids are stored on a concrete storage pad that was designed to be an integral part of the manure solids removal facility. These features allow researchers to quantitatively measure the solids removal efficiencies of both mechanical and gravitational separation technologies.

Mechanical Screen Separator. A mechanical screen separator (Agpro, Model 24L) was chosen to remove bulk manure solids. This type of system is already being employed in some Mississippi dairies and represents a solids separation technology that is feasible for some Mississippi dairy producers. The separator uses an inclined stainless steel screen to filter bulk solids out of the waste-stream. As bulk solids accumulate on the inclined screen a conveyor belt scraps them upward across the screen to be discharged onto the storage pad.

A 304.8 mm (12-inch) PVC pipe was installed to connect the existing drain line to the mechanical screen separator. Through the use of two 304.8 mm (12-inch) globe valves, the waste-stream can be diverted directly to the gravitational settling basin. This provides a failsafe mode when mechanical problems are encountered with the separator. In addition, diverting the waste-stream directly to the gravitational settling basin allows researchers to determine the trapping efficiency in a "gravitational settling basin only" operational mode. A diagram of the two operational modes tested is shown in Figure 2.

Gravitational Settling Basin. Sand removal from the waste-stream was made possible by adding a gravitational settling basin (GSB) to the research facility. The wastewater passes through the MSS and then empties into the GSB which, in turn, empties into a three-stage anaerobic/facultative lagoon system. The design of the GSB was dictated (and somewhat compromised) by the lack of elevation (fall) from the existing wastewater discharge outlet and the primary lagoon (approximately 91 cm). While the 50.8 cm of active settling depth in the final design was sufficient for research purposes, it must be cleaned out frequently (approx. every three days). The design criteria used in designing the GSB was based on many factors including: frequency of flushing, quantity of flush, sand utilized, and detention time.

Concrete Storage Pad. The manure solids separation facility is basically a 14.63 x 22.86 meters (48 x 75 feet) concrete bunker. The facility is approximately 1.83-meters (6-feet) below the ground surface due to the location of the existing flush drain line. The slope of the storage pad floor (1:10, rise:run) is such that all types of equipment (skid-steer loader or tractor with front-end loader) can easily move in and out of the facility, even in wet weather conditions. The size of the storage pad was dictated by the desire to be able to store manure solids and waste sand for about 90 days. This allows the manure solids and waste sand to be stored during the wet winter months when it is both environmentally and agronomically inefficient to land apply waste.

MATERIALS AND METHODS

Wastewater and manure solids samples were collected after a sampling period of three days. Several different wastewater parameters were analyzed, including: BOD_5, total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), orthophosphate (O-PO_4), total phosphate (T-PO_4), potassium, and total solids (non-volatile and volatile).

Wastewater Samples

Wastewater samples were collected at the post-MSS location and at the post-GSB location (lagoon). Figure 2 shows where the samples were removed for both the MSS on-line and off-line operational modes. Flow measurement weirs, connected to bubbler-equipped ISCO wastewater samplers were installed at these locations. Flow-rate was recorded every 10 minutes and flow-weighted samples were taken every 18,927 liters (5,000 gallons) by the ISCO samplers. The samplers also totalized the flow. Samples were taken while the MSS was on-line and off-line. The flow-weighted samples were collected and taken to the lab to be analyzed for BOD_5, NH_3-N, TKN, O-PO_4, and T-PO_4. All tests were conducted according to *Standard Methods for Examination of Water and Wastewater* (APHA 1989), with the exception of TKN, which used the Hach modification of the standard method. The nutrient analyses were all colorimetric, with final determination performed using a Baush &Lomb Model 601 spectrophotomer. BOD_5 measurements were made using a YSI Model 58 Dissolved Oxygen Meter and a Model 5730 Sensor.

Manure Solids Samples

Samples were taken from two separate piles (MSS and GSB solids) while the MSS was on-line. When the MSS was off-line, samples were taken from one combined pile of solids removed from the GSB. In either case, the volume of the pile(s) was determined using the coordinate method. Ten representative core sub-samples were taken from each pile, these sub-samples were then placed in a bucket and mixed to obtain a composite sample. While the MSS was on-line, two composite samples were retrieved (one from each pile). Three 50 ml samples were then extracted from each of the composites and weighed to obtain a wet weight. The 50 ml samples were then dried in a drying oven (103-105 °C) and weighed to obtain a dry weight (total dry solids). Next the dried samples were ashed in a muffle furnace for 40 minutes at 550 +/- 50 °C. These samples were then weighed to calculate amount of non-volatile solids for each sample. Methods for calculating total solids and non-volatile solids are similar to those found in the *Standard Methods for Examination of Water and Wastewater* (APHA 1989).

Calculations for moisture content (wet basis), bulk density, total dry solids, non-volatile solids (sand), and volatile solids were made for each sample. By measuring the volume of the solids pile and calculating the bulk density, the mass of each pile was obtained (mass = volume * bulk density). The solids from the MSS and GSB were also tested for potassium, TKN, and $T\text{-}PO_4$. in the Mississippi State Chemical Laboratory.

RESULTS

Wastewater Samples

Wastewater samples were collected with the MSS both on-line and off-line; therefore, both systems represented in Figure 2 were tested. An analysis was made on a percentage increase or decrease for levels of TKN, $NH_3\text{-}N$, $T\text{-}PO_4$, $O\text{-}PO_4$, and potassium from the post-MSS location to the post-GSB location, while the MSS was on-line and off-line.

TKN measured in mg/l had an average decrease of 1.94 percent when the MSS was on-line and an average decrease of 38.04 percent while the MSS was off-line. $NH_3\text{-}N$ was also found to have decreased in concentration. 2.29 percent when the MSS was on-line and 18.12 percent when the MSS was off-line.

Total phosphorus ($T\text{-}PO_4$) concentrations decreased by 11.32 percent when the MSS was on-line. However the $T\text{-}PO_4$ concentrations increased by 14.45 percent when the MSS was off-line. This is probably due to the inefficient trapping of the GSB at the end of the three day testing cycle, i.e., it was full. This condition caused most of the settled manure solids in the GSB from previous flushes to be re-suspended and, thus, discharged from the GSB.

Ortho-phosphate concentration ($O\text{-}PO_4$) decreased 2.53 percent with the MSS on-line and a 15.59 percent with the MSS off-line. Potassium concentrations decreased with the MSS on-line and off-line by 8.92 and 32.79 percent, respectively.

Manure Solids Samples

TKN, total phosphorus, and potassium concentrations were measured for the solids removed by the MSS and GSB. These measurements were also done with the MSS on-line and off-line. Total mass removal (kg/day) was much greater while the MSS was off-line and the flow was routed directly to the GSB (Figure 3). This is probably due to the reduced velocity of the waste-stream when the MSS is on-line, thus allowing much of the sand-load to drop out of suspension. The average removal of non-volatile solids (kg/day) was doubled by leaving the MSS off-line (Figure 4). The average amount of volatile solids removed (kg/day) was about the same when the MSS was on-line and off-line (Figure 5). The mass of non-volatile solids (kg/day) was significantly higher for solids removed from the GSB compared to solids removed by the MSS (Figure 6). The opposite was true for mass of volatile solids (kg/day), which were higher for MSS solids than for GSB solids.

The percentage of volatile and non-volatile solids removed from the GSB was impacted very little by the operation of the MSS as can be seen in the second and third bars of Figure 7.

Of the solids exiting to the lagoon, the percentage of non-volatile solids were higher when the MSS was off-line compared to when it was on-line (Figure 8).

The bulk densities calculated for GSB solids while the MSS was on-line and off-line ranged from 0.2678 - 0.8927 grams/cubic centimeters depending on the amount of total solids removed. The average percent moisture content for MSS solids was found to be 77.29 percent, while GSB solids had a moisture content of 42.63 percent. MSS and GSB solids combined (MSS off-line) had a moisture content of 50.16 percent, approximately equal to that of the GSB solids when the MSS was on-line.

Manure solid samples were also analyzed for TKN, T-PO_4, and potassium with the MSS on-line and off-line. TKN (kg/day) for MSS solids ranged from 0.30 - 0.61 and from 0.30 - 1.04 for GSB solids when the MSS was on-line. While the MSS was off-line, the GSB solids ranged from 1.44 - 2.35 kg/day of TKN. T-PO_4 (kg/day) for MSS solids ranged from 0.05 - 0.08 and from 0.05 - 0.19 for GSB solids when the MSS was on-line. While the MSS was off-line, the GSB solids ranged from 0.24 - 0.32 kg/day of T-PO_4. Potassium (kg/day) for MSS solids ranged from 0.04 - 0.10 and from 0.03 - 0.14 for GSB solids when the MSS was on-line. While the MSS was off-line, the GSB solids ranged from 0.20 - 0.28 kg/day of potassium. Overall, the nutrient levels in kg/day were increased when the MSS was off-line.

SUMMARY

The most interesting observation was the reduction in overall mass removal when the MSS was on-line. Total mass removal (kg/day) was much greater while the MSS was off-line as compared to when the MSS was on-line. Since the screen of the MSS restricts the wastewater flow somewhat, the velocity is reduced. This allows much of the sand load to drop out of suspension and settle in the delivery pipeline upstream of the MSS.

The average amount of volatile solids removed (kg/day) was about the same when the MSS was on-line and off-line. The mass of non-volatile solids (kg/day) [predominantly sand] was significantly higher for solids removed from the GSB compared to solids removed by the MSS. The reverse was true for mass of volatile solids (kg/day), which were higher for MSS solids than for GSB solids.

There was a higher percent reduction for most nutrient levels tested on wastewater samples when the MSS was off-line, with the exception of T-PO_4 concentrations, which increased by 14.45 percent when the MSS was off-line. The increase in T-PO_4 may be due to the inefficient trapping of the GSB at the end of the three day testing cycle, i.e., when the GSB was full of solids.

TKN concentrations were decreased by 38.04 percent when the MSS was off-line, indicating that significant quantities of nutrients can be stripped from the waste-stream using these technologies.

FUTURE WORK

Further tests need to be done to measure the amount of total solids (volatile and non-volatile) being discharged to the lagoon when the MSS is on-line and off-line. This would facilitate determination of overall nutrient, and BOD_5 removal from the waste-stream.

Representative wastewater samples need to be recovered and analyzed from the waste-stream prior to entering the MSS. This was attempted, but satisfactory samples have not yet been obtained. This will facilitate nutrient and BOD_5 concentration measurement at three different locations within the treatment train. This will allow researchers to identify the specific removal capacity of each component in the treatment train.

Future work on the manure solids separation facility is needed to determine the overall contribution of the MSS in a dairy waste treatment system.

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Figure 1. View of the Manure Solids Separation Facility (MSSF).

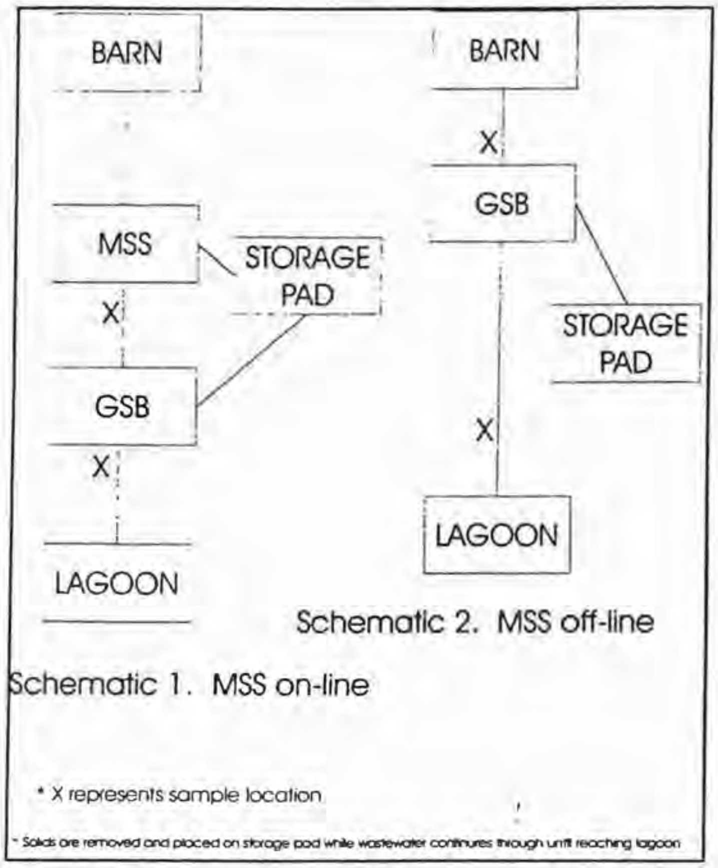

Figure 2. Flow diagram of Manure Solids Separation Facility (MSSF).

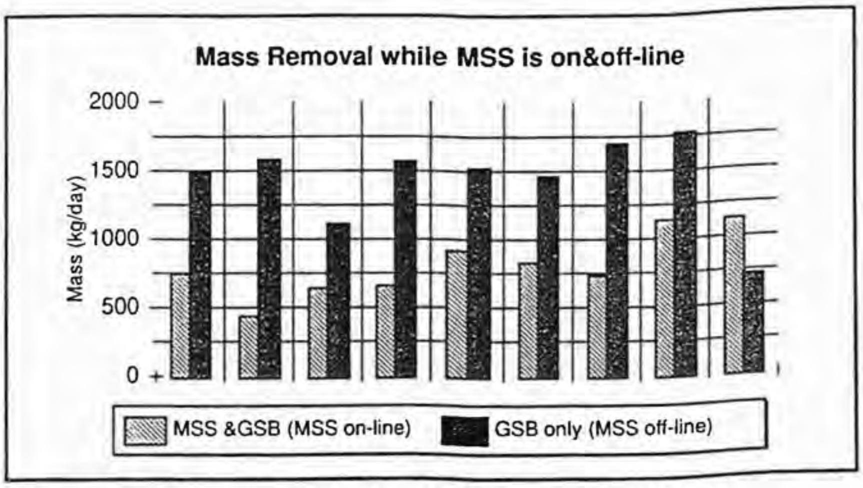

Figure 3. Mass removal when MSS is on and off-line.

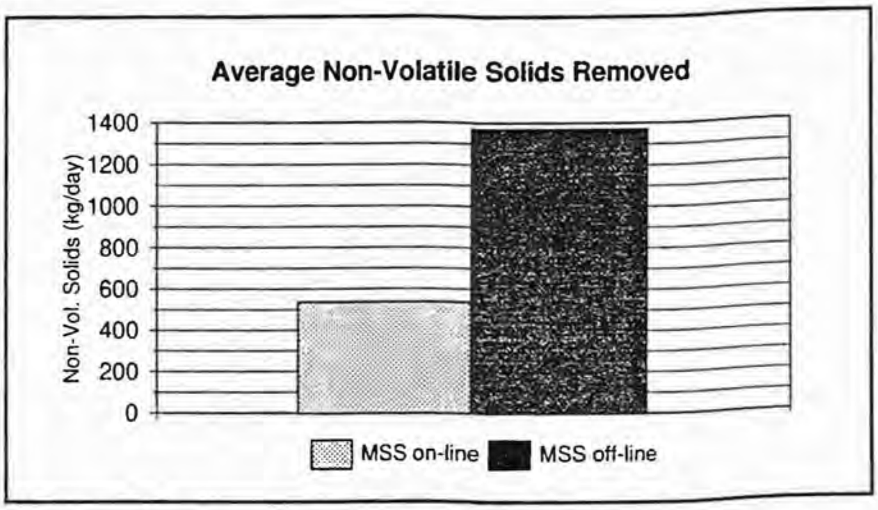

Figure 4. Average non-volatile solids removed.

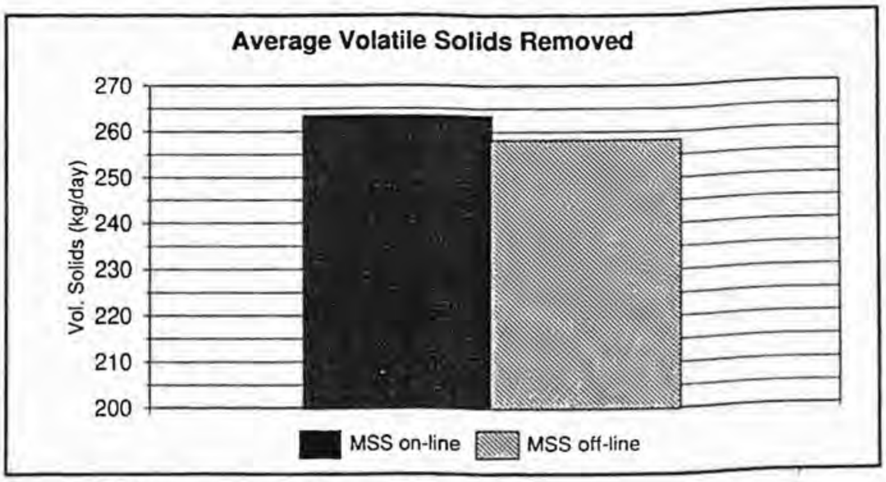

Figure 5. Average volatile solids removed.

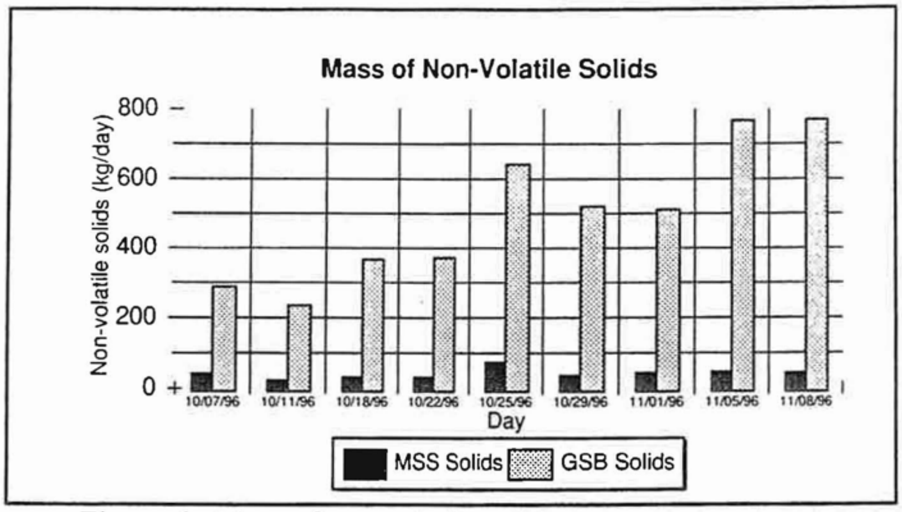

Figure 6. Mass of non-volatile solids.

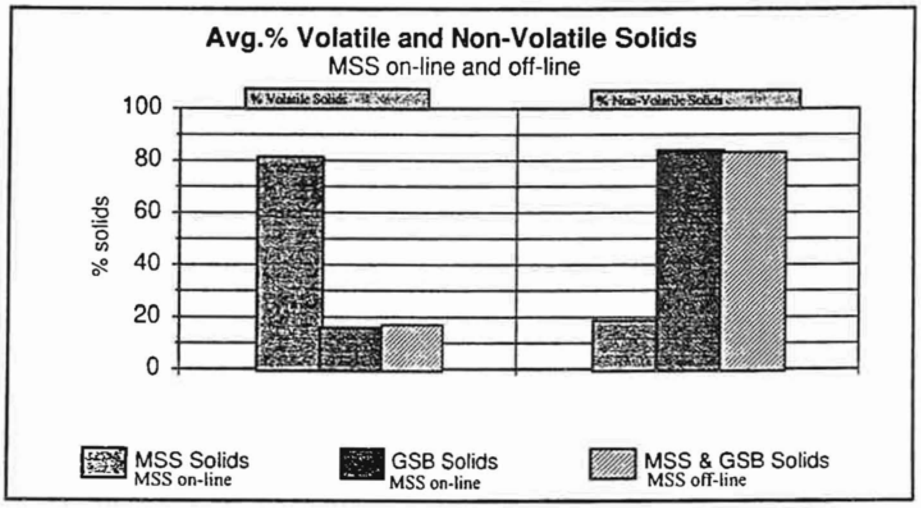

Figure 7. Average percent volatile and non-volatile solids.

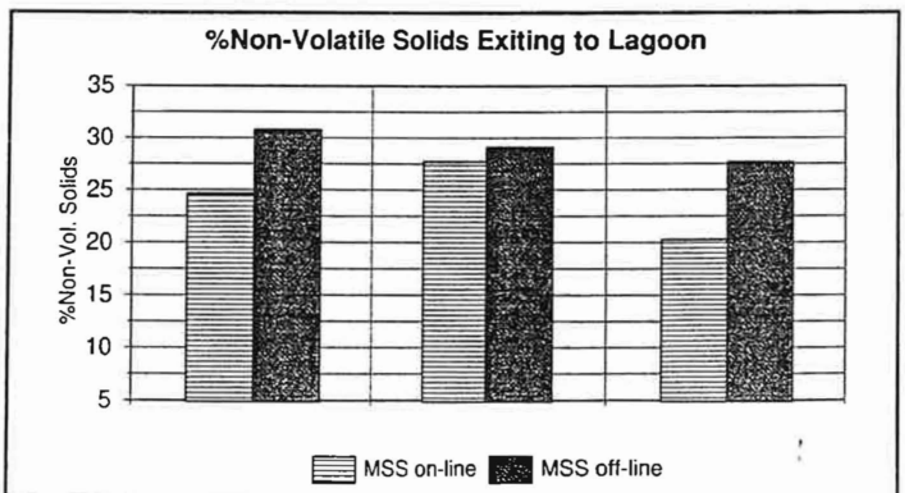

Figure 8. Percent non-volatile solids exiting to lagoon.