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Material Balance and Physical Characterization of the Various Streams in the Clarification Station of a Palm Oil Mill

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Abstract

The main function of the clarification station of a palm oil mill is to separate the pure oil from the other undesirable constituents like non-oil solids (N.O.S.) and water. The aim is to achieve minimal oil loss in the sludge discharge through optimal utilization of all machineries involved. The efficiency of the station depends on the performance of the clarification tank and the type of centrifuges used. This can be determined by measuring the flow rates of and applying the "material balance" principle to the various streams in the station. The constituents of the various streams can be characterized by centrifugation and optical microscopy. Results show that for the mill under study, a 78% efficiency in oil separation for the clarification tank could be achieved. A comparison of the Alfa Laval separator and the Stork centrifuge revealed that the former was more efficient in removal of N.O.S. and water from the underflow, while the latter was better for oil recovery. The constituents of the recycles from these two machines were different. Much optimization is needed for efficient operation. Two main types of N.O.S. were identified. The "middle layer," obtained by centrifugation, consisted of plant cells bloated with oil whereas the heavier sediments were plant cells either containing very fine oil droplets or completely devoid of oil. The "middle layer" constituted about 20–25% of the recycle streams. The nature of the oil from the separator was mainly of Type II whereas that from the centrifuge was of Type III.

INTRODUCTION

The processes in a palm oil mill can be divided into stations according to their functions. They are the sterilization station, threshing followed by the press station, and finally the clarification station which has the main objective of separating the pure oil from the other unwanted constituents such as non-oil solids and water. This must be carried out with a minimal oil loss in the discharge through optimal utilization of all the machineries involved.

The main equipment installed in the clarification station is shown diagrammatically in Fig. 1. The liquor from the press is first passed through a vibrating screen to remove any coarse particles. It then flows to the horizontal clarification tank which is a long rectangular tank divided into three compartments by partitions so arranged across the tank that the crude oil passes in turn beneath and over them. The oil that rises to the surface is skimmed and drained into the pure oil tank. The underflow goes to another retaining tank before it passes through a desander. A strainer is also installed for further removal of coarse particles. The desander and the strainer are discharged periodically.

The underflow is then processed by two different types of nozzle centrifuges. These two types of machines have the same function of separating more oil from the underflow and discharging some solids and water, but their throughputs and working principles are different, and so are their efficiencies.

The efficiencies of the clarification tank and individual centrifuge or separator used can be characterized by its separation efficiency based on "material balance" of the various streams (*1*). This material balance takes into account the flow of materials in and out of the system. Its efficiency also depends on the physical characteristics of the feed material which is affected by its constituents. A compromise is to be reached between the

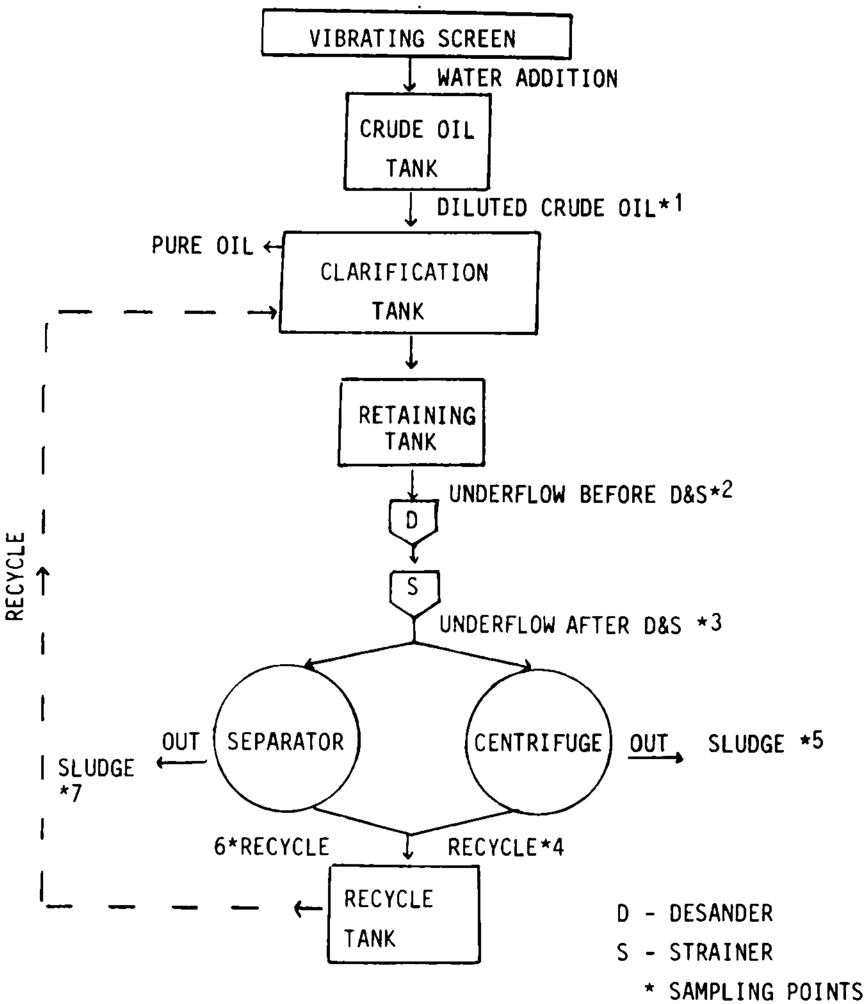


FIG. 1. The main equipment installed in the clarification station of a palm oil mill and the locations of sampling points.

acceptable level of oil loss via the discharge and the composition of the required material in each stream.

In most of the older mills, only centrifuges were installed. The newer mills employ only separators. A comparative study of these two types of machines from two different mills will not be strictly valid owing to the large variables involved in the fresh fruit bunches and processing conditions. A mill with these two types of machines running simultaneously side by side, such as the one chosen for this study, would thus be most suitable, and a comparison between them can then be made.

In the milling operation, optimization of the chemical engineering aspect can be achieved through better design and efficient process control. From the chemical point of view the proper control of resident time and temperature that affect the physical chemistry occurring in each station can be optimized too, but little is known of the nature of the solids and of the oil as they are separated and conveyed to the next stage. Further optical microscopic examination and quantification of the oil content at various stages of processing of the crude oil mixture in terms of their constituents as they are processed will give a better understanding of the clarification process from the physical aspect of palm oil extraction from the mesocarp of the fruit.

EXPERIMENTAL

Sampling points were devised at strategic locations in the clarification station as illustrated in Fig. 1. Sampling, at hourly intervals, was started as soon as the sludge discharge was available and continued until the presses were shut down at the end of the working day.

The flow rates of the discharge sludge from the Alfa Laval separator (model PAX 410) and Stork Centrifuge (type DC 6000) were measured with fixed volume rotating basculators over a specific time. The volume of diluted crude oil was determined similarly. The recycle flow rates of the Alfa Laval separator and Stork centrifuge were estimated by the time taken to fill up a fixed volume container.

The percentage of water, non-oil solids, and oil was determined by gravimetric, drying, and Soxhlet extraction procedures. The percentage volume of each zone of oil, water, and solids was determined by centrifuging the samples in a calibrated glass tube at 760*G* for 20 min. Portions taken from the different zones of the centrifuged samples were observed under an optical microscope, and photographs of the plant cells and oil droplets were taken. The sizes of these particles were then determined. The nature of the oil from the discharge sludge was categorized and quantified using methods established previously (*2*).

A material balance calculation is included in the Appendix.

RESULTS AND DISCUSSION

The constituents of the samples in terms of oil, water, and non-oil solids varied after each stage of processing (Fig. 2). The greatest reduction in oil content was after the clarification tank where as much as 78% of oil was skimmed off. The remaining 22% of the total oil remained in the underflow slurry, and this then went through the desander before it was further processed by the centrifuge and separator. The water content and non-oil solid contents of the recycle from the separator were much lower than those from the centrifuge. For every tonne of underflow processed, the separator was more efficient in terms of non-oil solids and water removal but in terms of oil recovery the centrifuge was better as less oil was discharged (Table 1). It is also noted that 48% of the influent from the centrifuge was recycled to the clarification tank while only 7% from the separator was recycled. The recycle from the separator had a very much higher oil content compared to that from the centrifuge. The sludge discharged from the separator was also found to have a higher oil content, on a dry basis, compared to that from the centrifuge.

When the various samples were centrifuged at 760*G*, they separated into different zones. Oil, being the least dense, floated to the top, whereas solids sedimented to the bottom. Immediately above the solids was the water layer. Intermediate between the water and the oil was a zone labeled as the "middle layer." The percental volume of each zone is illustrated in Fig. 3. The liquor from the press, when centrifuged, separated into two zones of oil and solids, but when water was added, a middle layer became visible. The oil contents of the different zones are shown in Table 2. The solids and the middle layers varied considerably in their respective oil contents. The water zone contained the least percentage of oil while the middle layer had the highest oil content. The oil layer consisted of oil only.

No gradual decrease of oil content of the solids collected from the various sampling points within the station was noted, indicating that once the solids were introduced into the clarification station, no further oil removal from them took place. The solids were mainly cell debris and unruptured plant cells, some bearing small droplet of oil, while the majority were just filled with protoplasm (Fig. 4). Even after centrifuga-

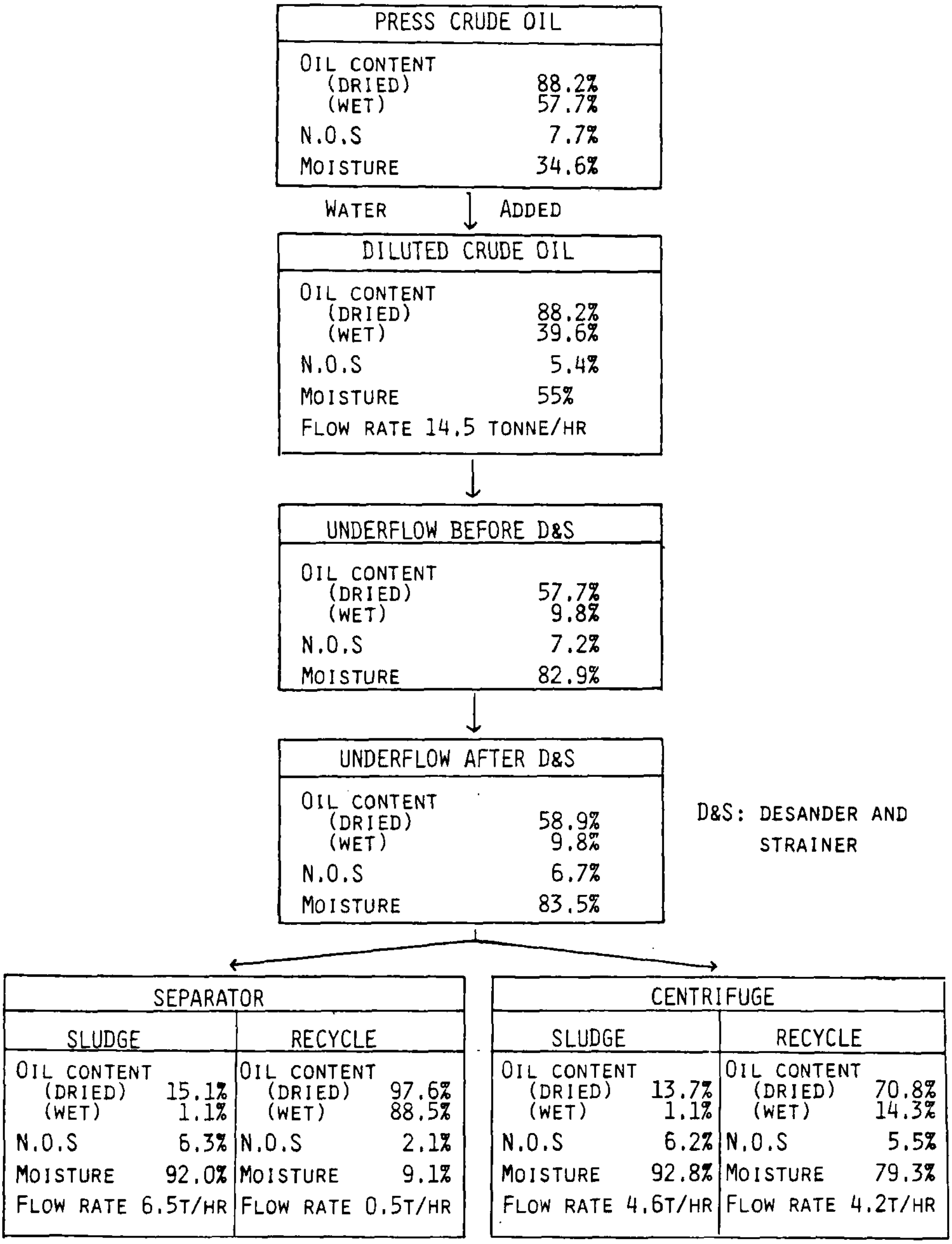


FIG. 2. Summary of results on the constituents of samples collected from the various sampling points in the clarification station.

TABLE 1
Performance of Clarification Tank, Separator, and Centrifuge

	% Efficiency		
Unit	Oil recovery	N.O.S. removal	Water removal
Clarification tank	78	—	—
Separator	66 ± 15	98 ± 8	99 ± 6
Centrifuge	70 ± 17	48 ± 6	58 ± 2

TABLE 2
Oil Contents of the Different Zones Obtained after Centrifugation of Samples Collected from Various Sampling Points in the Clarification Station

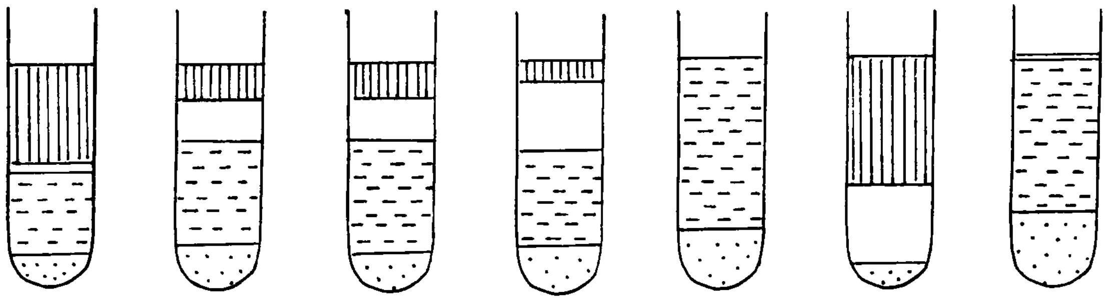
	Oil content on a dried weight basis (%)	
Zone	Range	Mean[a]
Middle layer	62.9–88.7	79.5
Water	0.5–5.8	1.3
Solids	12.1–31.9	19.0

[a]Average of 66 samples.

tion the solids were not completely free of water, and in the space among the cells there were some oil droplets. The long axis of these plant cells ranged from 10 to 150 μm (mean 86 ± 25 μm) while the short axis ranged from 13 to 100 μm (mean 52 ± 16 μm).

The water layer did not contain any cells, but all the oil present was in droplet form with a diameter ranging from 3 to 18 μm (mean 4 ± 0.8 μm). The same droplet sizes were found for those in the underflow right to the final discharge stage, indicating that there was no comminution of oil droplets in the clarification station.

Most of the oil in the middle layer were found in the plant cells (Fig. 5). The sizes of the cells in the middle layer ranged from 95 to 270 μm (mean 171 ± 42 μm) along the long axis while the short axis ranged from 45 to 170 μm (mean 99 ± 26 μm), but the majority were bigger than those found



SAMPLING POINTS	1	2	3	4	5	6	7
OIL %	45.5	11.9	15.6	11.8	-	74.7	-
MIDDLE LAYER %	5.7	14.8	15.6	25.1	-	20.0	5.6
WATER %	34.6	56.2	56.9	46.8	77.5	5.0	66.4
SOLID %	14.2	17.1	13.8	16.4	22.5	-	28.2

OIL   MIDDLE LAYER   WATER   SOLIDS

FIG. 3. Samples from the various sampling points in the clarification station showing the percentage volume of each zone after centrifugation.

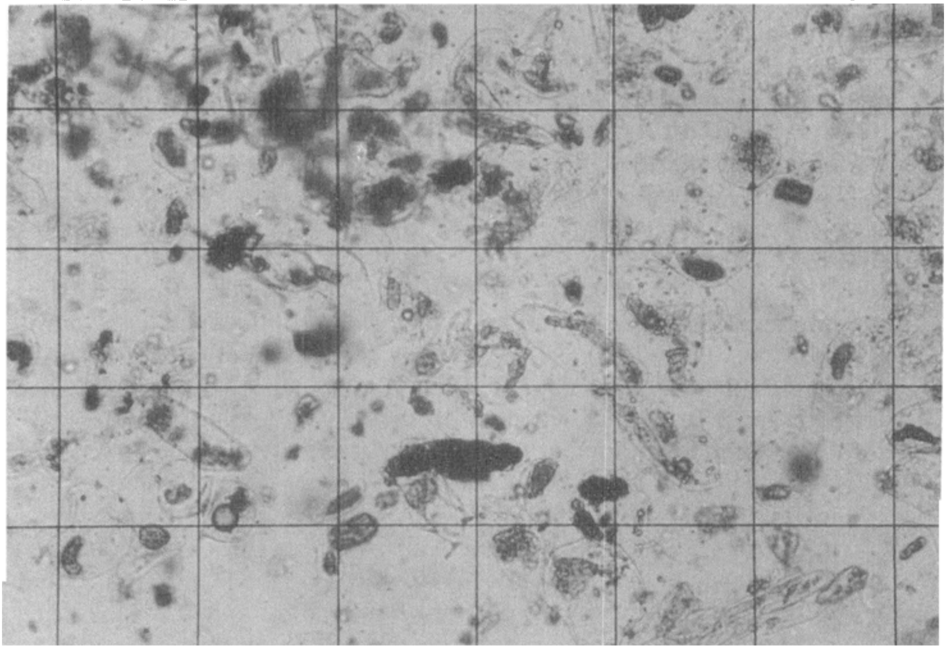


FIG. 4. Plant cells and plant cell debris found in the solids (sediment) zone after centrifugation.

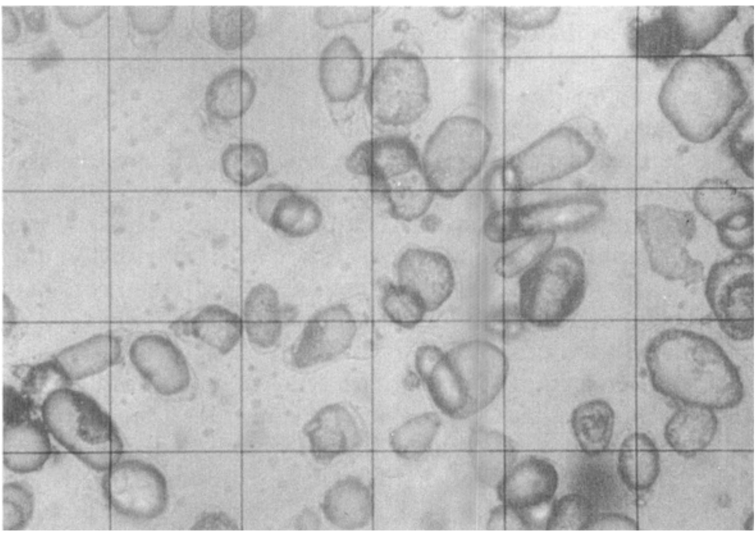


FIG. 5. Oil cells found in the middle layer after centrifugation.

in the solids (sediment). A big oil droplet may occupy the whole volume and hence take on the shape of the cells. Sometimes the oil exists as a very small round drop within the cell. It would appear that there is a maximum volume that the oil is capable of existing in round droplet form within the cell limited by its own cohesive force. Due to its high average oil content of 79.5%, the middle layer is of greatest interest in terms of oil recovery consideration.

In the mill, separation of the oil mixture into distinct zones by the centrifuge and separator (at ~1500*G*) is not posible due to its short resident time. Thus, if a small percentage of these middle layer type oil cells were to get into the sludge, it would contribute to a high oil content. Thus, sludge that contains big oil cells is an indication that the machines are not properly adjusted in terms of oil separation or the underflow constituents are not optimal.

The "middle layer" was found mainly in the recycle and constituted about 20–25% of the recycle streams. There was no significant increase in the middle layer as the day's processing went by. This could perhaps be due to the fact that the cells were very fragile and a slight mechanical shear force would rupture them, thereby releasing the oil, and the ruptured cells would then sediment rapidly or the increase would be too small to be detected. The accumulation of the middle layer is a problem because when it gets too thick it forms a barrier between the underflow and the oil layer in the clarification tank, thereby preventing free oil droplets from floating up. As long as the middle layer does not accumulate excessively, oil recovery from it is still possible in the clarification tank (*3*).

A previous study showed that the oil in the sludge in the clarification station can be categorized into three types according to the methods by which it is separated (*2*). Type I is minute free oil droplets. Type II is mainly oil in the oil cells which can be separated only if the cell walls were first ruptured by celluclast and then washed with sodium dodecyl sulfate to separate it from the cell debris. Type III, the residual oil, is not observable under the microscope but is quantified by hexane extraction on the dried solids.

The nature of the oil from the two types of machines were similar but differed in percentage composition (Table 3). The sludge from the separator contained more oil of Type II because the cut-off point in the machine was at the region where the lighter oil-bearing cells were found which would pass into the sludge whereas the cut-off point for the centrifuge was very much nearer to the heavier solid zone where all the lighter oil cells would go into the recycle instead. Thus the oil from the

TABLE 3
Nature of the Oil from the Sludge Discharged from the Separation and Centrifuge (mean values)

Sample	Oil type		
	Type I, wt%	Type II, wt%	Type III, wt%
Separator	35	39	27
Centrifuge	22	25	53

sludge of the centrifuge was mainly of Type III. The various separated phases are illustrated very clearly in Fig. 3, but in the mill, due to the shorter retention time and continuous running, the phase cut-off was not as distinct.

CONCLUSION

At present the oil content of the sludge discharged is well documented and the oil loss is based on it. However, the exact quantity of the discharge is not easily available because it is not usually measured accurately and thus the actual oil loss is not known. Estimates are usually based on the ratio of fresh fruit bunches processed to the oil produced (w/w) for the day. This study shows that with the incorporation of some form of measuring devices in the mill coupled with material balance consideration, it is possible to assess the absolute oil loss and the efficiency of the machines used.

At present there is a lack of on-line detection of the different constituents of the various streams for process control. However, using the technique outlined above, it is possible to differentiate the nature of the oil loss. It is important to recognize that only a certain proportion of oil loss in the sludge can possibly be prevented while the rest is inevitably lost when using the existing process and machineries. Thus the free oil droplets are almost impossible to recover using the existing type of centrifuges because these droplets, due to their minute size, are extremely stable and do not deemulsify easily. Oil in the cells could be reduced to a minimum by optimizing the milling conditions while the Type III oil is inevitably lost. Excessive oil loss in this way may contribute to effluent treatment difficulties.

In view of the polluting effect of the sludge discharged, the industry is looking for alternatives to avoid the use of dilution water altogether in the clarification station. In one such alternative, the highly viscous liquor from the press is directly subjected to separation by decanters. At this stage it may be worthwhile to consider how the composition and nature of each stream can affect the separation efficiency, and what limitations the nature of the materials may have on the capability of these machines. Great difficulty is forseen in attempts to achieve a distinct phase separation of the viscous oil-in-water emulsion from an inhomogeneous and variable solid. Further processing of partly separated phases is definitely necessary.

APPENDIX

The performance of the clarification tank, separator, and centrifuge were estimated from the following equations:

% efficiency of oil separation of clarification tank

$$= 100\% - \frac{(oU)(Ts + Tc)}{(oDCO)(rDCO) + (oRs)(rRs) + (oRc)(rRc)} \times 100\%$$

where oU = oil content of underflow

$Ts + Tc$ = throughput of separator + throughput of centrifuge

$oDCO$ = oil content of diluted crude oil

$rDCO$ = flow rate of diluted crude oil

oRs = oil content of recycle from separator

rRs = flow rate of recycle from separator

oRc = oil content of recycle from centrifuge

rRc = flow rate of recycle from centrifuge

% efficiency of centrifuge/separator in oil recovery

$$= \frac{\text{(oil content of recycle)(flow rate)}}{\text{(oil content of underflow)(flow rate)}} \times 100\%$$

% efficiency of centrifuge in N.O.S./water removal

$$= \frac{\text{(N.O.S./water content of sludge)(flow rate)}}{\text{(N.O.S./water content of underflow)(flow rate)}} \times 100\%$$

The efficiency of N.O.S. and water removal of the separator was calculated from the content of the recycle because the sludge could possibly be diluted by the balance water.

% efficiency of separator in N.O.S./water removal

$$= 100\% - \frac{\text{(N.O.S./water content of recycle)(flow rate)}}{\text{(N.O.S./water content of underflow)(flow rate)}} \times 100\%$$

Acknowledgments

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