PARTICLE COUNTER AND TURBIDITYMETER ANALYSIS OF RECLAIMED SECONDARY EFFLUENT

S. Oh, R. Iranpour*, R. Mayer, D. Gumaer, Y.J. Shao, O. Moghaddam, G. Garnas, V. Varsh, J. Langley, J. Wilson
Applied Research, Hyperion Plant, Bureau Management
Bureau of Sanitation, CLA

***Hyperion Treatment Plan**
12000 Vista Del Mar
Playa Del Rey, CA 90239

ABSTRACT

These are the results of a study to understand the turbidities observed in the secondary effluent supplied by Hyperion Treatment Plant (HTP) of City of Los Angeles (CLA) for reclamation. These turbidities are higher than desired, and appear to be the main reason for the frequent occasions when the reclaimed water exceeds the 2 NTU limit specified by Title 22. Simultaneous data from a Laser Particle Counter (LPC) and the turbidity meter at the HTP pumping station have been tabulated from March 11 to March 23, 1999, and subjected to several forms of analysis that show clearly that the observed turbidities are caused by a particle population covering the size range from about 7 μm to more than 15 μm. Another population was also discovered to be present, in the size range from 2 μm to around 5 μm. This population was not detected by the turbidity meter, and its concentration is often, but not always, anticorrelated with the density of the larger particles or turbidities. This study is an example of the opportunities for using particle counters to gain detailed understanding of secondary clarifier and tertiary filter behavior that would be difficult to observe in any other way. Other applications of particle will also be presented, for example, water, air and hydraulic oil.

KEYWORDS

Particle count, turbidity, reclamation, correlation, filtration, secondary effluent

INTRODUCTION

Turbidity meters have been used for many years to find the quality of water. They operate reliably, and their simplicity makes them inexpensive compared to particle counters, so they can be expected to remain the primary instruments for monitoring the particle content of water. However, understanding their limitations shows the benefit of using particle counters when more detailed information is needed.

These measurements have been made as part of a larger effort by the Applied Research Group to support the plant in its effort to understand the turbidity problem associated with the HTP secondary effluent in sufficient detail to make recommendations for overcoming it. The other studies have included conductivity measurements, a bench scale treatability study in which HTP secondary effluent was pumped through filters with differing pore sizes to determine their effect on the turbidity, and an examination of the hydraulics of the distribution channel system. The particle counter study has been much more informative than any of these previous approaches.

In this study the counter was set to classify particles into six ranges, with a tentative intention of making a later analysis with a larger number of narrower intervals, although this turned out not to be necessary. This study shows that a particle counter can provide several benefits, including the following:

I. Determining in details the effectiveness of the filters in a reclamation plant.

II. Providing guidance for designs of future reclamation processes, e.g., filtration systems.

III. Greatly improving results compared to studies that use only a turbidity meter.

IV. Saving costs and achieving more comprehensive results compared to treatability studies that measure turbidity after the use of filters of different pore size.

V. Finding relationships between these results and other process control parameters.

There are very few references on particle counter application to wastewater. Iranpour et al, (1999) did this investigation at HTP for the CLA Sanitation. Many other references have been reviewed which are mostly related to water application: e.g., Harris et al., 1996; Faris et al., 1992; Hunt et al., unknown; Sommer et al., 1990; Goldgrabe et al., 1993; Yoo et al., 1995; Lewis et al., 1991; Hargesheimr et al., 1992 and 1995; Sethi et al., 1997; Treweek et al. 1977; Van Gelder et al., 1999; McTigue et al., 1998.

IMPORTANT ISSUES ON PARTICLE COUNTER

Particle counter has not been extensively applied to wastewater industry, however, there are several important applications in water industry, such as drinking water treatment, food processing and membrane processing. They also are used in semiconductor industry for air analysis as well as checking the machine condition by hydraulic oil.

Historically they have been used a lot in the drinking water plants. For example, Las Vegas Water District uses them to monitor the water quality that is too clean for turbidity data in 1979. In 1988, Georgia implemented the rules for refiltration efficiency when they had Giardia and Cryptosporidia problems. Water particle counter was accepted widely to comply with the rules for log removal of particulate when Cryptosporidia was outbroken in Milwaukee, 1993. Finally, American Water Works Association (AWWA) formed a committee to develop standard methods for Water Pollution Control (WPC) use in drinking water industry.

In short particle counting in water treatment has greatly improved process monitoring, prediction of Cryptosporidium and Giardia outbreak and tighter control of treatment process for specific sizes.

Major problems with this instrument, similar to other technologies, are poor accuracy and repeatability. A few of physical parameters need to be examined, such as sensitivity limit, signal to noise ratio and counting efficiency which are of interest when compared different equipment from different vendors.

EXPERIMENTAL SETUP

The on-line laser particle counter (LPC) system was installed at HTP next to the West Basin Effluent Pump Plant located on the southwest corner of the plant. A sample waste stream for the LPC was diverted from the inlet of an existing Hach turbidity meter that monitors effluent from clarifier modules 1 and 2. ¼ inch O.D. tubing was used to connect the LPC inlet to this sample source and the LPC outlet to a drain. In the LPC the sample flows through a 750 µm by 750 µm optical flow cell. Each particle passing through the sensor generates a signal corresponding to its size.

In the MetOne™ Model PCX LPC system the laser measurement cell is interfaced through an RS-232 to RS-485 converter to a controlling computer running Vista Version 1.1. Vista is a proprietary Windows-based water quality software package that runs the complex functions of the LPC and stores the vast amounts of data collected. The system is in a NEMA 4-rated enclosure, with a power supply and various cables and tubing needed for the cell and the electronic components. The entire system occupied only about three square feet of floor space.

For the present measurements the Vista program was commanded to assume a flow rate of 100ml/min through the cell, to take a reading every 10 minutes, and to classify the particles into six size ranges. The six ranges were 2-3 µm, 3-5 µm, 5-7 µm, 7-10 µm, 10-15 µm and 15-750 µm. These size ranges are set up based on state or federal regulations or the sizes corresponding to *Giardia* or *Cryptosporidium.*

EXPERIMENTAL PROCEDURE

After a shakedown period and a one-week trial run the LPC took samples for two weeks, from March 11 to March 23, 1999. Data were recorded every 10 minutes, 24 hours a day, in six separate size ranges totaling over 12,000 data points. The data were then transferred to a Microsoft Excel format and downloaded to a desktop PC for analysis.

Plant turbidity data from the same location were obtained for comparison with the particle counts. HTP uses a Bailey DCS system for data gathering and storage. The PI-Process Book for Windows 95™ (Ver 1.30) was used as an interface to download data from Bailey to a desktop PC. These data were also stored in Excel format and analyzed as follows.

TIME SERIES PLOTS

Time series plots have been prepared with the particle count and turbidity results displayed on both linear and logarithmic vertical scales. As the larger particles are present in the smallest densities, the logarithmic scale emphasizes the variations in the densities of the larger particles more than the linear scale does, and provides the most emphatic visual demonstration of the extremely close correspondence between the turbidity readings and the densities of the larger particles. The logarithmic scale graph is attached and labeled as part (a) of each daily figure. Parts (b) and (c) of the figures are, respectively, the histogram and the scatter plot of the same daily data. Thus, Figure 2(a) is the logarithmic plot of the data for March 11, Figure 2(b) is the histogram and Figure 2(c) the scatter plot for the same day. March 11, 13 and 20 were chosen for display here because they represent the extremes observed during the measurement period. The other days resemble one or the other of these extremes, or fall somewhere in the middle.

Many phenomena are evident in these plots. For example, there are prolonged periods during which the density in the 5-7 µm size channel is lower than the density in either the 3-5 µm channel or the 7-10 µm channel, implying that the density distribution as a function of particle size during these times was clearly bimodal. During the times that the 5-7 µm channel had higher readings, the differences from the densities in the 7-10 µm channel were usually small, indicating that the particles at least 7 µm in size formed a prominent shoulder on the side of the peak formed by the densities in the three channels in the interval from 2 µm to 7 µm. All of this is strong evidence that two particle populations are present.

Another form of evidence is the great difference between the behaviors shown in the different size channels. The 7-10 µm, 10-15 µm, and 15-750 µm size channels showed nearly perfect agreement in their fluctuations, so that these channels clearly were observing different portions of the same population of relatively large particles. Likewise, there were such strong correspondences between the 2-3 µm and 3-5 µm densities that these channels also were easily recognized as containing different portions of a population of small particles. However, the variations of the particle densities in the 2-5 µm interval did not agree with the density variations in the three largest size channels (7-750 µm), but tended to vary oppositely with them, particularly in the period between 5:00 PM and 10:00 PM each day. The 5-7 µm size channel displayed an intermediate character, in the sense that earlier in the day it tended to fluctuate in step with the channels for the larger particles, but when the 2-3 µm and 3-5 µm count rates decreased around 6:00 PM, the 5-7 µm size channel did, too.

As the densities of the small particles varied more or less oppositely not only to the densities of the large particles but to the turbidity readings, it is clear that the response of the turbidity meter to the small particles was small or absent. Indeed, Figure 3(a) shows that notably low turbidities, approximately 3.3 NTU, were observed around noon of March 13, a day when the 3-5 µm density was in the range 6500-7000 particles/mL, but Figure 2(a) shows that the turbidity never dropped below 4.0 NTU on March 11, when the 3-5 µm density was 2000-3000 particles/mL.

Although it is clear that two populations of particles are present, distributed around two differing mean sizes, the plots also show that the shapes of these distributions were subject to substantial changes, sometime lasting hours to days. As a particularly emphatic example, Figures 3(a) and 2(a) show that the ratio of the 3-5 µm density to the 2-3 µm density was larger on March 13 than on March 11. Likewise, on most days rises in the total densities of the larger particles between 5:00 PM and 10:00 PM coincide with reductions of the ratio between the 7-10 µm density and the 10-15 µm density, and the 7-10 µm/15-750 µm density ratio.

SCATTER PLOTS

To gain a more comprehensive view of the relationships between the turbidity readings and the densities in the size channels, scatter plots were prepared in which the turbidities were the vertical coordinates in each plot, and the densities for the respective size channels were the horizontal coordinates. The plots were arranged in two columns, so that reading down the columns gives the size channels in increasing order. These groups of plots are designated as part (c) of each daily figure, so that Figure 2(c) is the scatter plot for March 11, and the sequence continues to Figure 4(c) for March 20.

As expected from the nearly perfect correspondence, in the time series plots, between the variations of the turbidities and those of the densities in the 10-15 μm and 15-750 μm size channels for many days, the scatter plots for those densities versus the turbidities show very little departure from a single diagonal line that slopes up from left to right. Some of the plots of the densities in the 2-3 μm and 3-5 μm size channels versus the turbidities show a fairly clear diagonal line shape sloping down from left to right, and this also is as expected from the apparently opposite variation in some time series plots.

However, many of the scatter plots showed more complex behavior, some of which was not expected from the time series plots. For example, on March 13, the 7-10 μm density vs. turbidity plot in Figure 3(c) shows two up-sloping straight lines diverging from each other to form a sideways V shape, and the 10-15 μm and 15-750 μm densities vs. turbidity show configurations that include nearly parallel diagonal lines. A hint of parallel lines is also present in the corresponding scatter plots in Figure 4(c), for March 20.

More complex shapes are present in many of the scatter plots. The shift in the behavior of the 5-7 μm channel observed in the time series plots is reflected in the scatter plots by the presence of points arranged in two intersecting lines, one sloping down and one sloping up. This plot in Figure 3(c), for March 13, resembles an upside-down T, and the one in March 14 (not shown), resembles an L rotated around 100 degrees counterclockwise. The 3-5 μm plot for March 14 and both the 2-3 μm and the 3-5 μm for March 16 (not shown), show lines of positive and negative slopes, resembling distorted V's that open to the left. The 3-5 μm plot in Figure 3(c) slightly resembles a fork with three unequal tines. The 2-3 μm and the 3-5 μm plots in Figure 2(c) for March 11 show two distinct groups of points and the corresponding plots for March 17 (not shown) show points arranged in a meandering line.

It is reasonable to interpret these groupings as reflecting changes in operating conditions during the day, and probably the changes in the particle distributions deduced from the time series plots. The BOD load on the plant changes inevitably, and operators or the control system may change the flows to the clarifiers according to changing influent flows. Identifying the times and operational parameters corresponding to these groupings might provide insight into physical, chemical or biological reasons for the behavior displayed in the plots.

CORRELATIONS

Correlation coefficients between turbidity and particle density were computed for each size channel for all the days, and the results are tabulated in Table 1. The high correlations for the 7-10 μm, 10-15 μm, and 15-750 μm size channels for most of the days are as would be expected from the nearly linear arrangements of points on the corresponding scatter plots. The few that are lower, such as for 7-10 μm on March 13, correspond to plots that depart from a linear configuration, but they all are consistent in showing positive correlations that are statistically significant at extremely high confidence levels, given the approximately 140 data points for each day and range used in the correlation calculation.

The smaller three size ranges display much more variable results. The 2-3 μm plots show the most frequent strong negative correlations, and positive only five of the fourteen days. It is clear from the scatter plots that the behavior in these size ranges often looks highly deterministic, but it is both much more variable from day to day than in the large size ranges, and usually not describable by a straight line. Hence, the great variation in the linear correlation coefficients and the frequent low correlations for these size ranges are also understood easily from the scatter plots.

Evidently, although there are individual days for which the correlations in the small size ranges have extremely high significance according to the conventional evaluation of confidence limits, these correspondences are only temporary. The most extreme case of unstable correlations occurs for the first two days of the data set, March 11 and 12. The correlations for the 2-3 μm, 3-5 μm, and 5-7 μm size channels are all greater than 0.7 on March 11 and less than -0.7 on March 12. In short, there is no significant long-term correlation between turbidity and the densities in these ranges, as shown by the averages of the correlations at the bottom of the table.

DISCUSSIONS AND CONCLUSIONS

The histograms for March 11 give the impression that there might be three populations: two relatively narrow peaks, and a broad background that gradually declines with increasing size. However, examination of the time series plots shows that in fact there are only two populations, each with a relatively broad and asymmetrical distribution. The 2-3 μm count rate is very well correlated with the 3-5 μm count rate, and the 7-10 μm, 10-15 μm, and 15-750 μm count rates are all very well correlated. The 5-7 μm count rate shows an intermediate character, displaying some variations that match those of the count rates of the larger particles and some that match those of the smaller ones.

The obvious explanation of these observations is that the corresponding variations in the count rates in adjacent size ranges show that these are portions of the same particle population, with a broad size distribution. On the other hand, the behavior of the particles in the population seen between 2 and 5 μm is clearly different from that seen in the ranges that are 5- 7 μm. The behavior seen for the 5-7 μm range is what would be expected if the two populations overlap in this range, and predominate at different times. Thus, the two peaks seen in the histograms in Figure 2(b) are the most prominent indication of two different populations.

The results also show that the large numbers of small particles observed on March 13 had little effect on the outputs from the turbidity meter. This is consistent with results presented by Hunt (199), who provides examples of turbidity meters responding weakly to particles smaller than 4 μm.

The particle counter provides reliable results because the design of the measurement cell and the recommended limit on particle density in the sample combine to give a very low probability that two particles would be in the laser beam simultaneously and would thereby be mistaken for a single larger particle causing the same momentary brightness reduction (Faris, et al., 1992). These considerations limit the maximum count rate to around 20,000 particle/sec or less, so the speed of the electronic detection system pose no limitation (Sommer, 1990a, b, c).

Considering that water reclamation is becoming increasingly important, the importance of particle counters in analysis of water quality is sure to increase. This study is an example of the opportunities for using them to gain detailed understanding of secondary clarifier and water reclamation process behavior that would be difficult to observe in any other way.

ACKNOWLEDGEMENTS

We would like to thank Bureau of Sanitation management for support and direction on this project. We would also like to thank Dr. Young Kim of USFilter and Chris McCampbell of MISCO for providing us with technical references on the subject.

REFERENCES

Faris, B., Schenk, S., Obermyer, L., Knudson, M. (1992) Issues Related to Accurate Estimation of Particle Removal Efficiency.

Goldgrabe, J., Summers, R., & Miller, R. (Dec 993) "Particle Removal and Head Loss Development in Biological Filters," Jour. AWWA, 85:12:94

Hargesheimer, E. E.& Lewis, C. M. (1995), "A Practical Guide to On-Line Particle Counting," AWWA Res. Fdn., Denver, CO

Hargesheimr, E. E., Lewis, C. M., & Yentsch, C. M. (1992). Evaluation of Particle Counting as a Measure of Treatment Plant Performance (50595). AWWA Res. Fdn., Denver

Harris, H. S., Kaufman W. S. & Krone R. B. (Dec. 1966) "Orthokinetic Flocculation in Water Purification," ASCE, vol92, no SA6, Proc. Paper 5027 PP95-111

Hunt, D.J. (199) Use of Particle Counting for Water Treatment Plant Optimization.

Iranpour et al. (1999) "Recent Particle Counter and Turbidity Results at Hyperion Treatment Plant," Report prepared for City of Los Angeles, Bureau of Sanitation

Lewis, C., & Manz, D. (1991) "Light-scatter Particle Counting: Improving Filtered Water Quality," Jour. Envir. Engrg., 117:2:209

McTigue, N. et al. (1998). National Assessment of Particle Removals by Filtration. AWWA and AWWARF. Denver, CO.

Sethi, V. et al. (Feb. 1997), "Evaluation of Optical Detection Methods for Water borne Suspensions," Jour. AWWA, 89:2:98

Sommer, H.T. (1990a) "Performance of Monochromatic and White Light Extinction Particle Counters," IES International Conference on Particle Detection, Metrology and Control, Feb. 5-7, 1990, Arlington VA.

Sommer, H.T. (1990b) Reliability and Count Accuracy of Optical Particle Counters, 36th Annual Meeting of the Institute of Environmental Science, Apr. 23-27, 1990. New Orleans, LA.

Sommer, H.T. (1990c) "Optical Single Particle Sizing of Liquid Suspensions," 2nd World Congress, Particle Technology, Sept. 19-22, 1990, Kyoto, Japan.

Standard Test Method for Measurement of Particle Count and Size Distribution in Batch Samples for Filter Evaluation Using and Electrical Resistance Particle Counter. ASTM Standard F662-86. ASTM, Philadelphia, 1992

Treweek, G. & Morgan, J. (1977) "Size Distributions of Flocculated Particles: Application of Electronic Particle Counters," Envir. Sci & Technol., 11:7:707

Van Gelder A., Chowdhury, Z., & Lawler, D. (Dec. 1999),"Conscientious particle counting" Jour. AWWA, 64:91:12

Yoo, R.S. et al.(Dec1995), "Microfiltration: A Case Study," Jour. AWWA, 87:3:38

Table 1- Correlation Coefficients of Particle Counts vs. Turbidities for Different Particle Size Ranges

Size Ranges	2.0-3.0	3.0-5.0	5.0-7.0	7.0-10.0	10.0-15.0	15.0-200
	Correlation Coefficients					
3/11/99	0.77	0.77	0.70	0.89	0.87	0.86
3/12/99	-0.71	-0.84	-0.72	0.84	0.89	0.89
3/13/99	-0.75	-0.78	0.02	0.67	0.93	0.94
3/14/99	-0.88	0.14	0.71	0.94	0.97	0.96
3/15/99	-0.44	0.10	0.21	0.74	0.66	0.71
3/16/99	-0.68	0.63	0.88	0.98	0.94	0.96
3/17/99	-0.77	-0.40	0.54	0.94	0.96	0.95
3/18/99	-0.46	-0.74	0.55	0.88	0.90	0.91
3/19/99	-0.42	-0.69	0.06	0.61	0.84	0.89
3/20/99	-0.25	-0.06	0.68	0.98	0.98	0.98
3/21/99	0.34	0.77	0.85	0.94	0.92	0.90
3/22/99	0.19	0.45	0.37	0.65	0.90	0.93
3/23/99	0.45	0.50	0.36	0.75	0.92	0.94
3/24/99	0.26	0.30	0.36	0.63	0.87	0.90
AVE ± STD	-0.24±0.54	0.01±0.60	0.40±0.42	0.82±0.14	0.90±0.08	0.91±0.07

Figure 1- Schematic Drawing of Met One Particle Counter

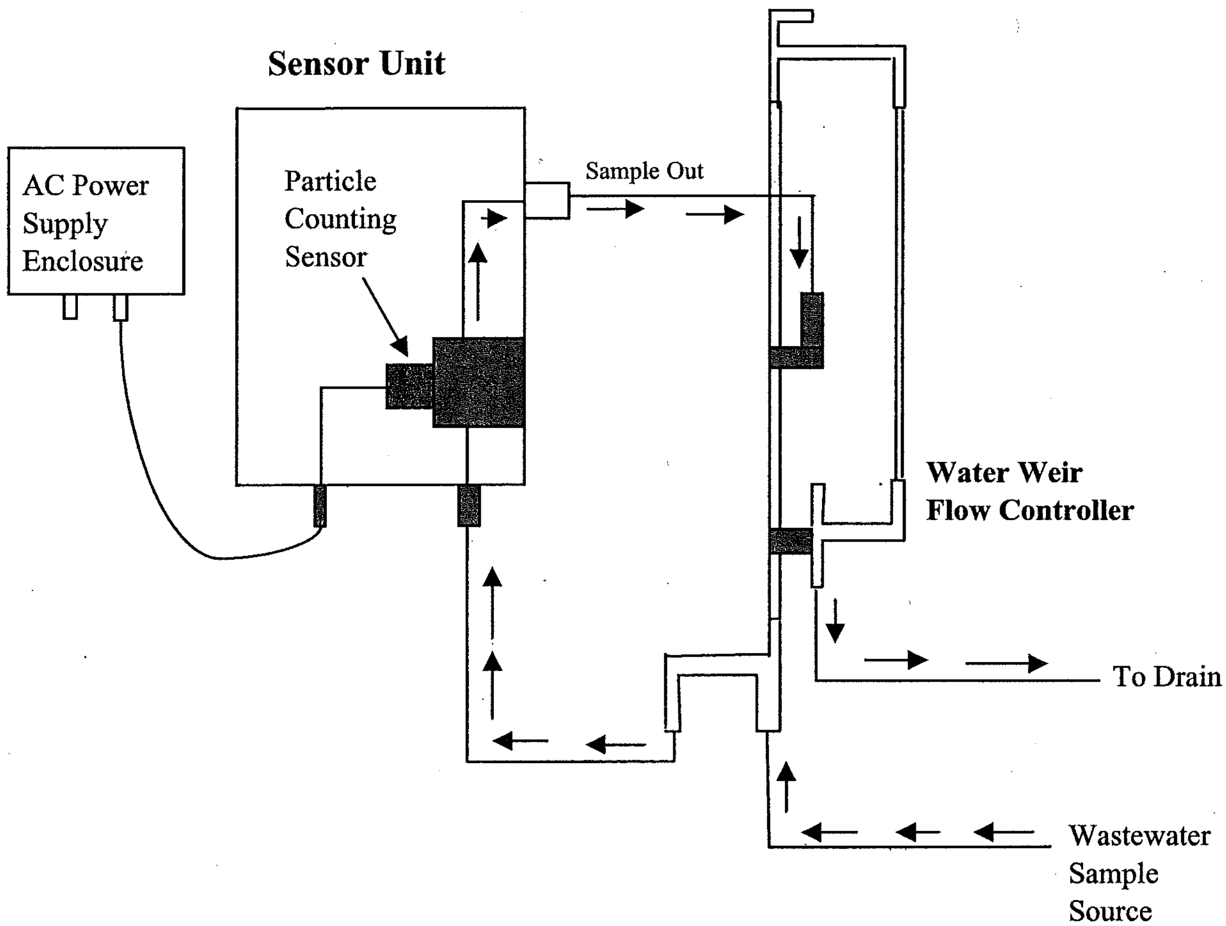
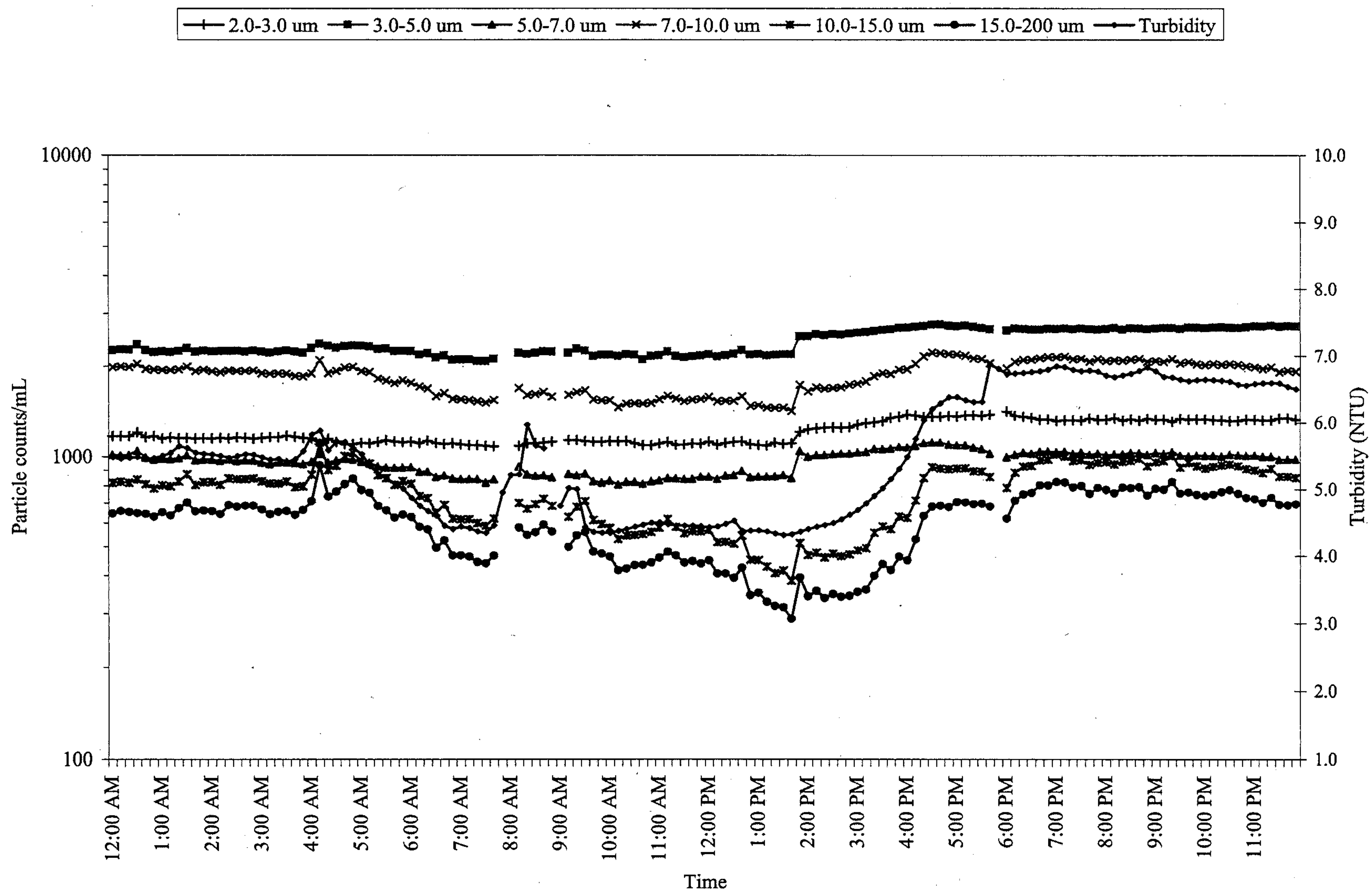
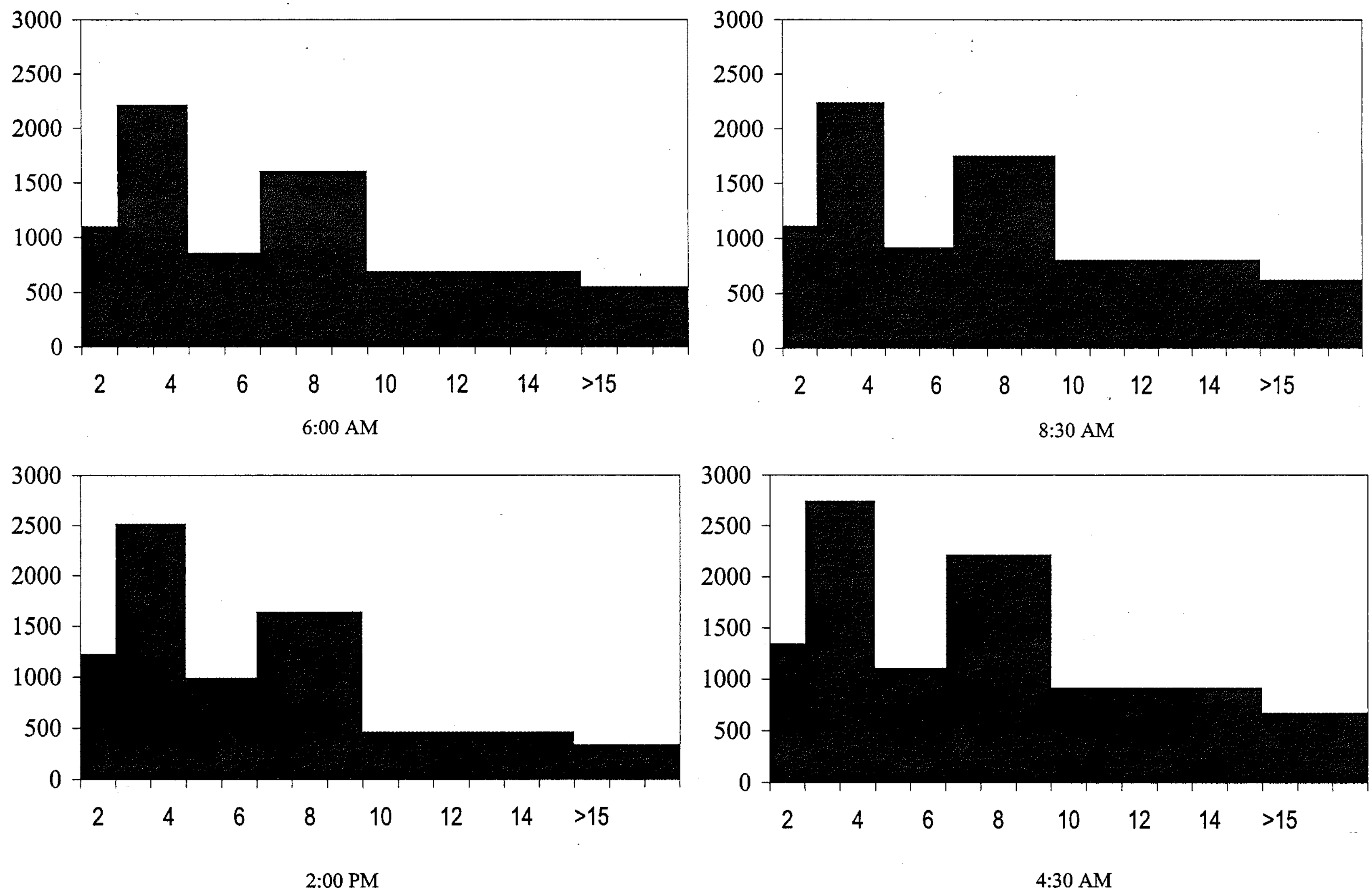


Figure 2- Particle Count and Turbidity of HTP Secondary Effluent Modules 1&2, 3/11/99



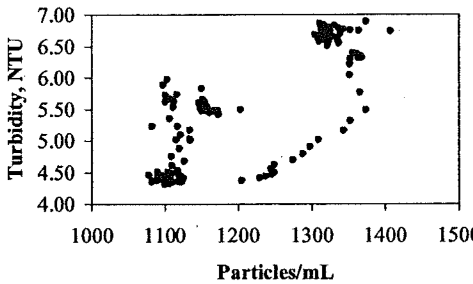
(a) Times Series - Log Scale

Figure 2- Continued.

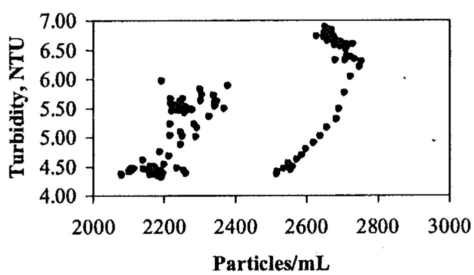


(b) Particle Count Distribution

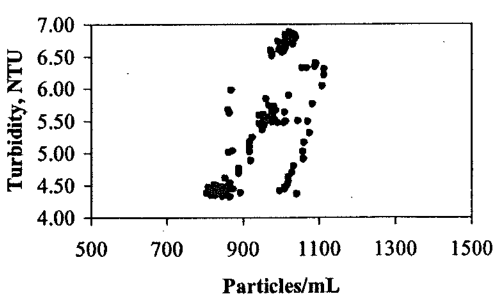
Figure 2- Continued.



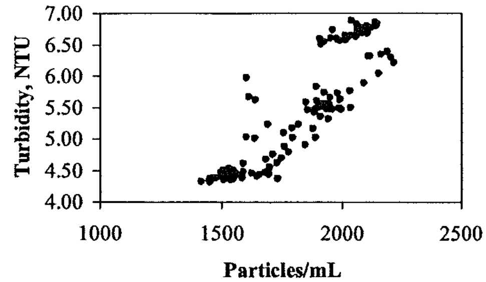
2.0-3.0 microns



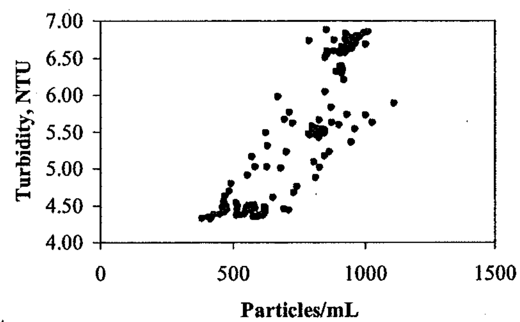
3.0-5.0 microns



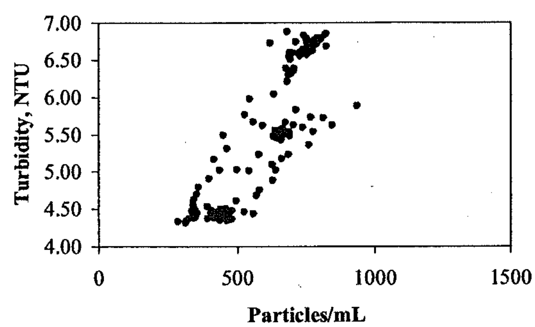
5.0-7.0 microns



7.0-10.0 microns



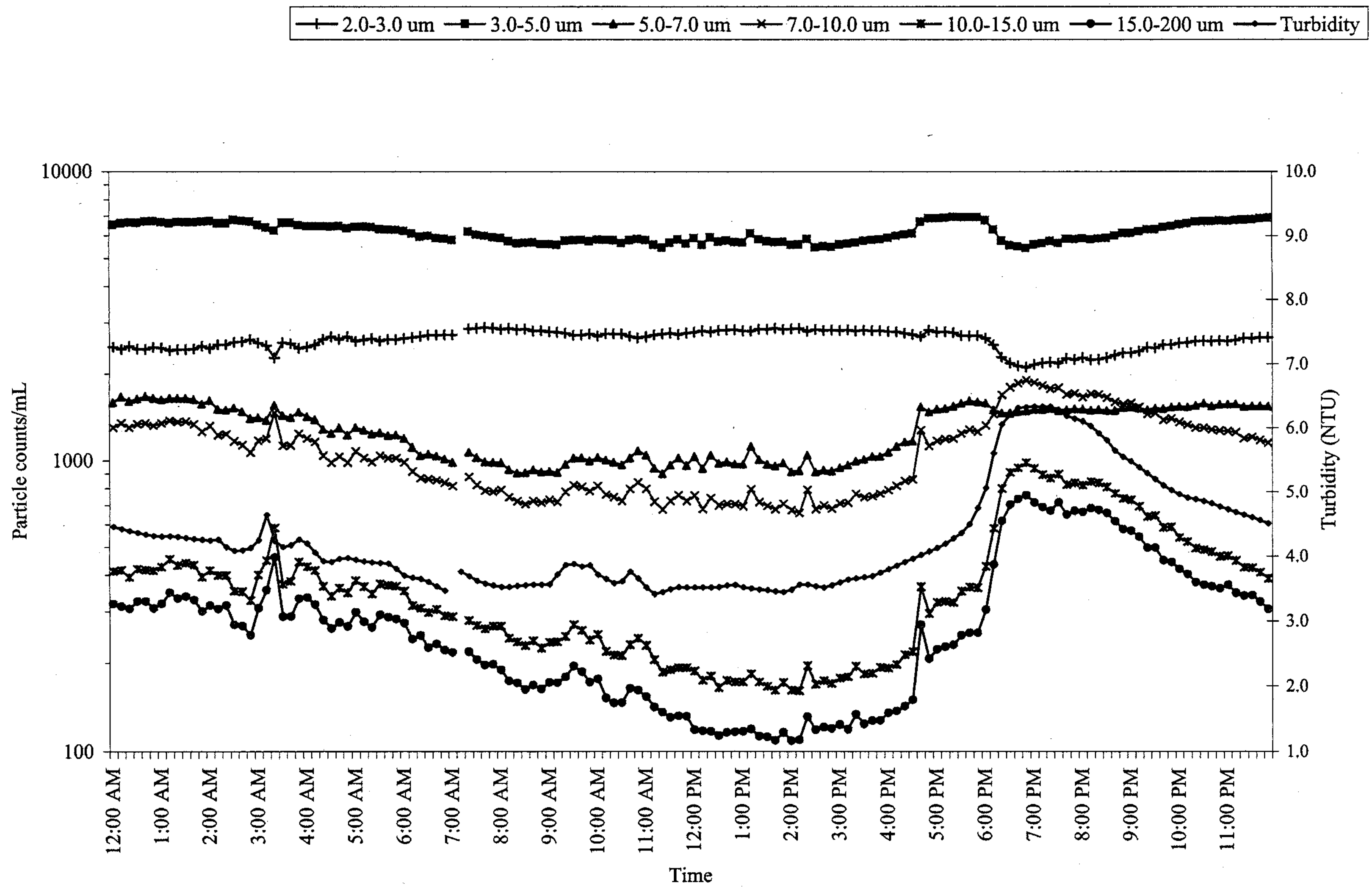
10.0-15.0 microns



15.0-200.0 microns

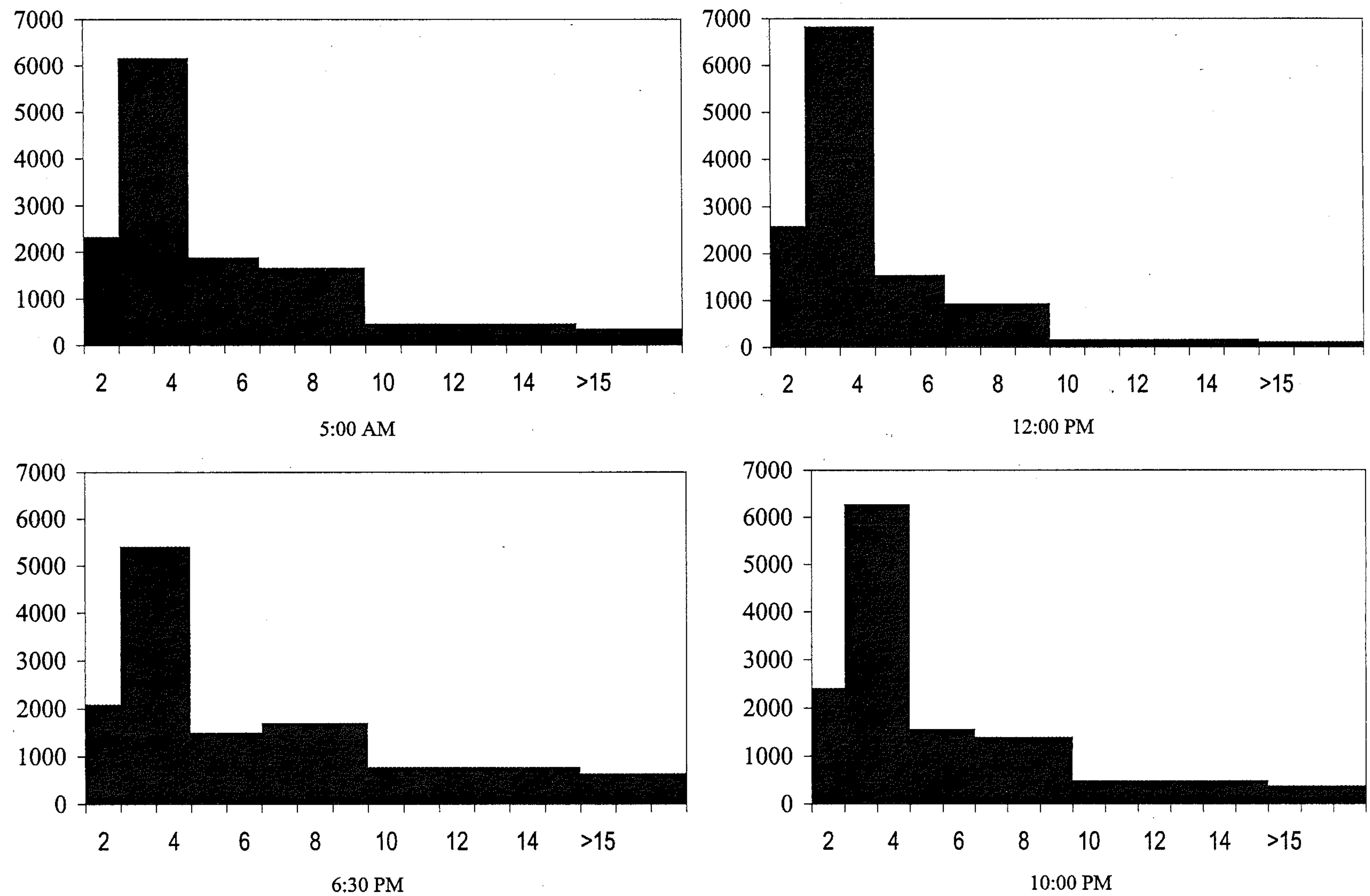
(c) Scatter Plot

Figure 3- Particle Count and Turbidity of HTP Secondary Effluent Modules 1&2, 3/13/99



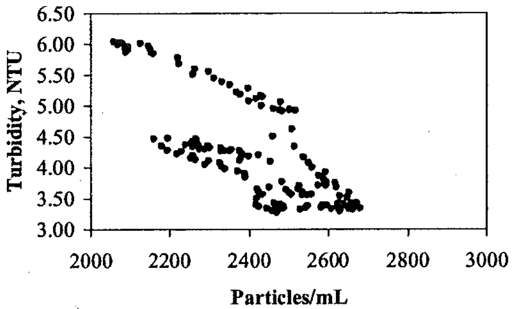
(a) Times Series - Log Scale

Figure 3- Continued.

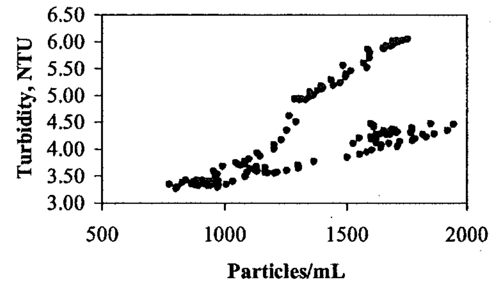


(b) Particle Count Distribution

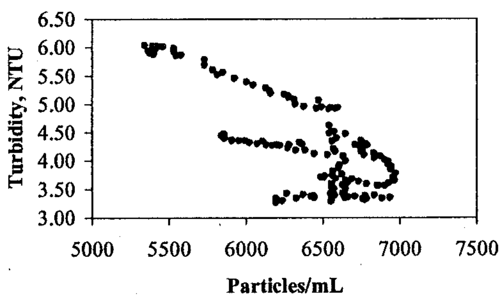
Figure 3- Continued.



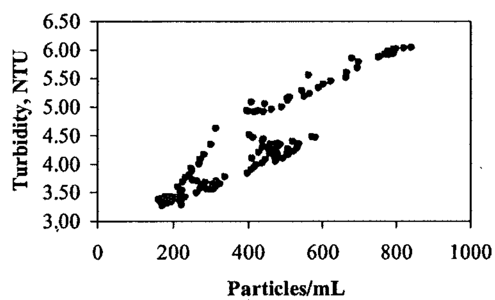
2.0-3.0 microns



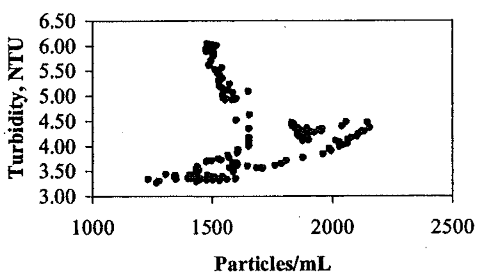
7.0-10.0 microns



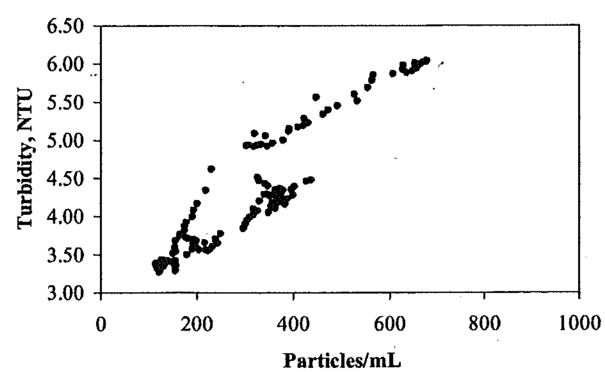
3.0-5.0 microns



10.0-15.0 microns



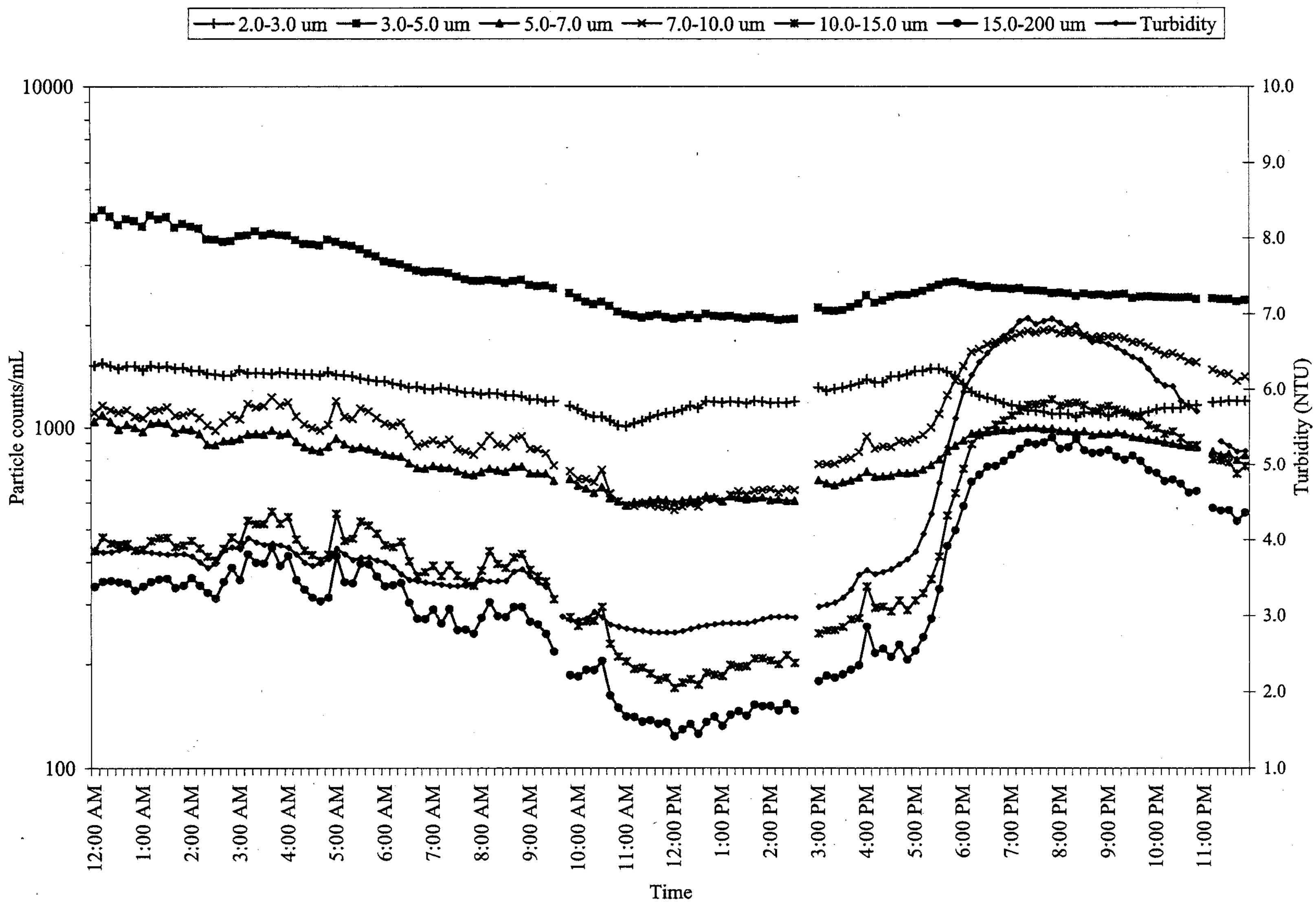
5.0-7.0 microns



15.0-200.0 microns

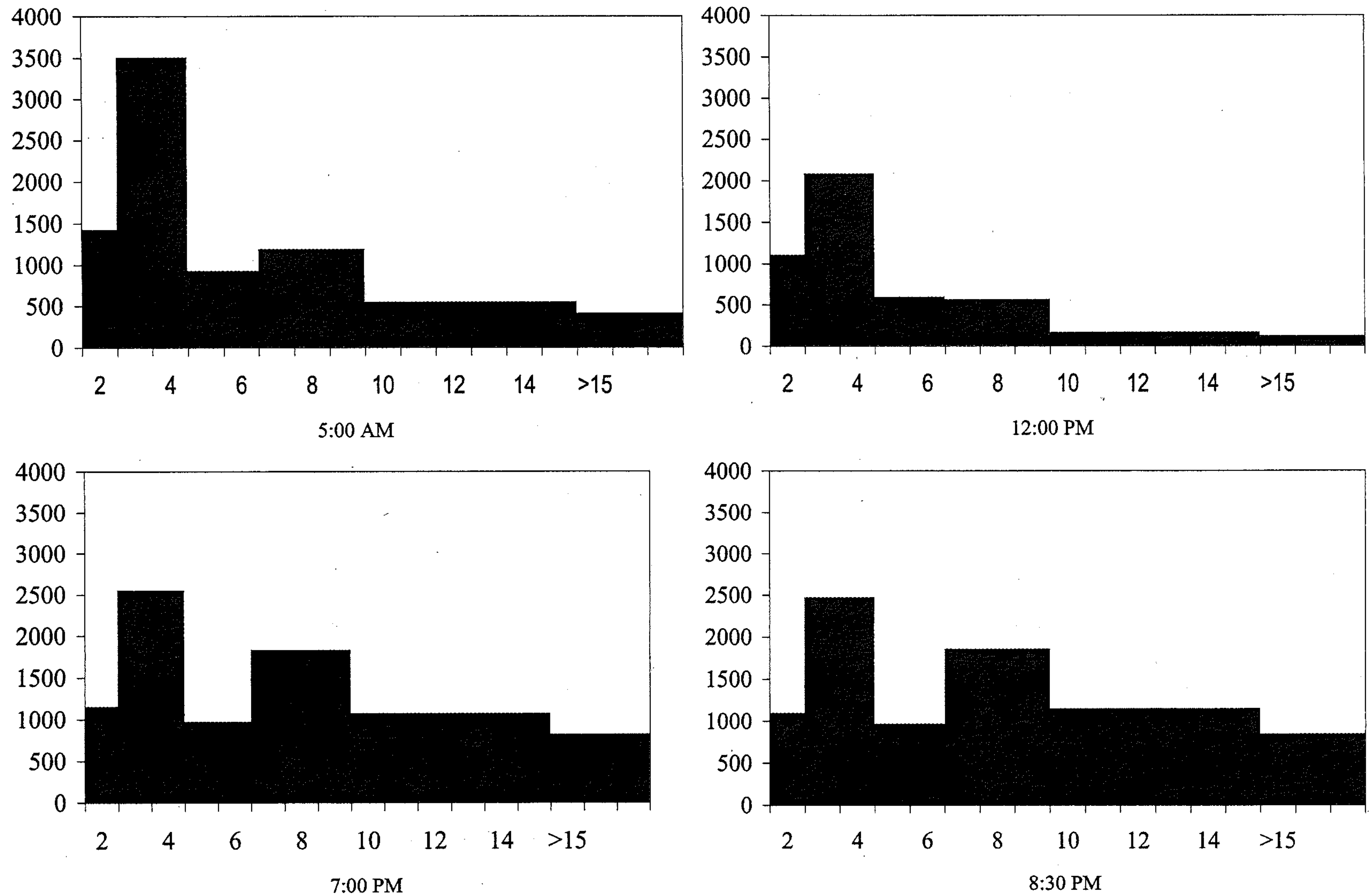
(c) Scatter Plot

Figure 4- Particle Count and Turbidity of HTP Secondary Effluent Modules 1&2, 3/20/99



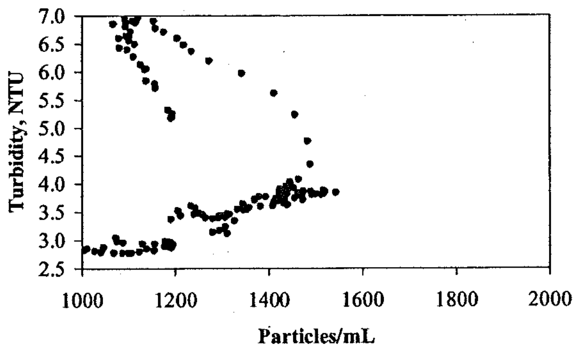
(a) Times Series - Log Scale

Figure 4- Continued.

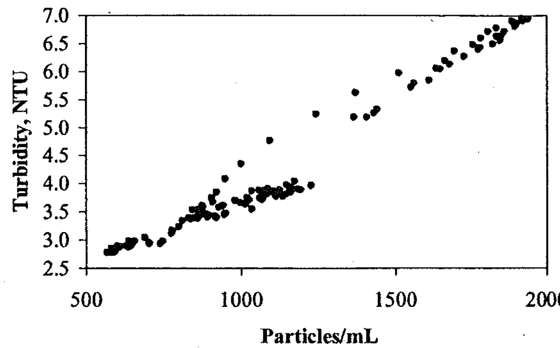


(b) Particle Count Distribution

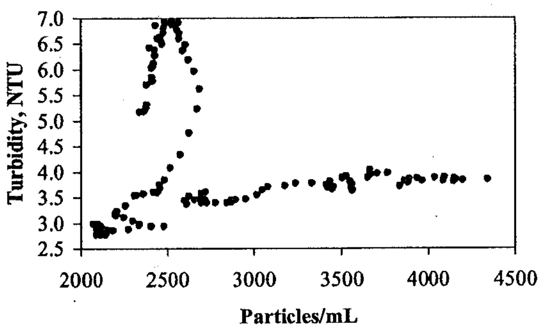
Figure 4- Continued.



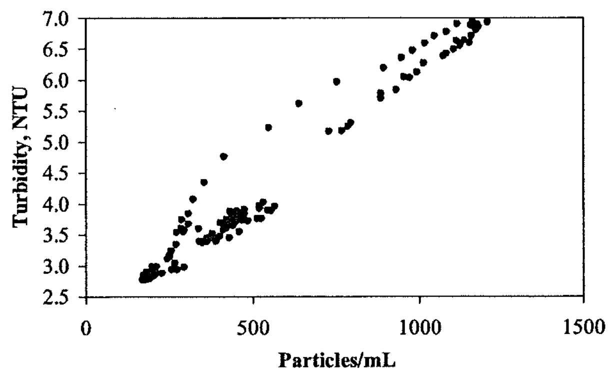
2.0-3.0 microns



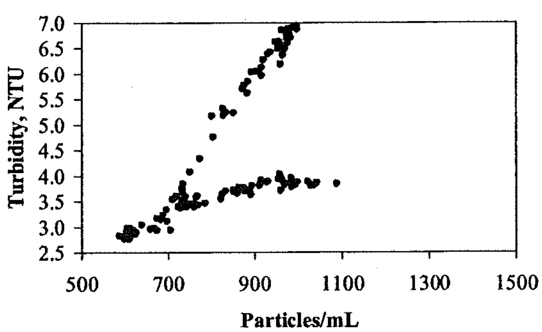
7.0-10.0 microns



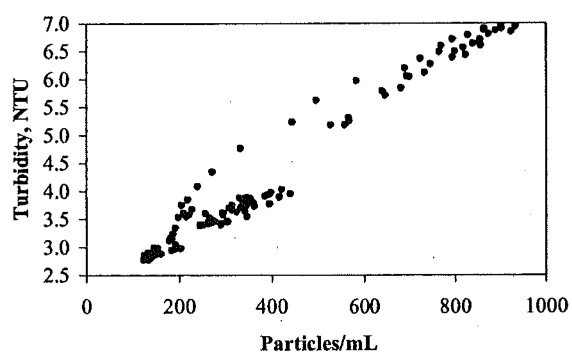
3.0-5.0 microns



10.0-15.0 microns



5.0-7.0 microns



15.0-200.0 microns

(c) Scatter Plot