AEROBIC BIO-OXIDATION OF THIOCYANATES:
DEVELOPMENT OF DESIGN PARAMETERS

Progress Report

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ABSTRACT

The source of coal conversion wastewater thiocyanates is reviewed. Based on laboratory studies, the biokinetics of aerobic degradation of thiocyanate is quantified and found to follow a "substrate inhibition model". A design curve based on theoretical and laboratory considerations is developed.

A material balance for sulfur and nitrogen as originally found in the SCN complex is presented. During aerobic degradation of SCN, sulfur goes to sulfate, and nitrogen goes to ammonia. During anaerobic degradation of SCN, sulfur goes to sulfide. Thiocyanate was the sole source of carbon, nitrogen, and sulfur available to the microorganisms during the course of the study.

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OBJECTIVE

The objective of this project is to develop a kinetic expression and material balance for nitrogen and sulfur for the biological degradation of aqueous thiocyanates, as found in coal conversion process wastewaters. This work is in support of DOE and PETC Programmatic activities for coal conversion process support in the area of environmental control technology development. It is anticipated that this work shall assist in the overall effort of developing environmentally acceptable coal conversion processes.

Progress Report

Overview:

I. Work during the term of the project to date involved developing batch biokinetics for the bio-degradation of SCN, and determining a material balance for sulfur and nitrogen during biodegradation.

A series of continuous culture reactors were constructed and started up. Each reactor is equipped with a special designed clarifier section which appears to be an improvement over the "Eckenfelder" model originally used. Each reactor is also outfitted with a Chemtrix Corporation pH controller and acid/base feed pump pair to facilitate operation.

Using thiocyanate, sulfate, ammonia, and nitrate measurements, an overall equation for biologically mediated SCN removal was found to be:

Since an abiotic aerated aqueous solution of KSCN is stable over time, it is concluded that the above reaction is in fact biologically controlled.

The literature contains references indicating qualitatively that high levels of SCN are toxic to biosystems. The following equation was found to best describe SCN aerobic biokinetics at pH ranges of 7.5[±]1₂ :

$$v = 2.4 / [1 + (62.5/\text{SCN}) + (\text{SCN}/1270)^6] \quad (ii)$$

where v = lb thiocyanate destroyed/lb VSS-day

SCN = mg/L thiocyanate in solution

The above equation indicates little difficulty in thiocyanate removals at SCN levels of less than 500 mg/L, and potential problems of process instability and marked effects due to "substrate inhibition" at higher levels of SCN.

SIGNIFICANCE OF SCN IN WASTEWATERS

(1) Existing coke plant biological waste treatment facilities are often operated with SCN as a control parameter. The plant operator relies on low effluent SCN levels as a prime indicator of phenolic degradation to low levels. From a technical viewpoint, this may be a rational approach since SCN inhibits phenol biodegradation, and SCN is found to be removed sequentially after phenolic removal. Often, however, extreme toxicity effects are minimized in steel industry practice via wastewater dilution. As an example, when traditional coking plants were located adjacent to a coal mine, mine water was frequently used for waste dilution prior to biological processing (1). This approach, however, may not be compatible with the water re-use considerations of the U. S. coal conversion industry, as projected for the 1980's and 1990's.

(2) Dephenolization via solvent extraction of a coal conversion wastewater stream may be expected to leave short chain organic aliphatics, ammonia, and thiocyanate for subsequent biological oxidation. Refractory PNA's are expected

to remain in the aqueous phase. If solvent extraction is utilized, a smaller biological plant should result, with SCN being a principal contributor to effluent "BOD". Such a plant would be designed with SCN removal chiefly in mind.

(3) As pointed out by Kleeberg (2), a Stretford process, as proposed for hot-gas clean up of H_2S , produces sodium thiosulfate and thiocyanate, in accord with the following side reactions involving the oxidation of product sulfur as follows:

In addition, as outlined by Dravo (3), HCN in the hot gas reacts irreversibly with "Stretford Solution" to produce additional NaSCN. This may be minimized by providing a "front-end" treatment to the hot gas in the Stretford system by reacting the product gas with a sodium polysulfide ($Na_2S_{(n+1)}$) solution in a separate absorber. In any event, a blowdown must exist to prevent NaSCN buildup.

Stretford wastes have been reported as toxic to biological wastewater facilities. Stretford solution consists of ADA (anthro quinone-disulfonic acid), sodium metavanadate, citric acid, and sodium carbonate. Although SCN levels of over 2,000 mg/L have been found in Stretford wastes, research

should be conducted to determine the relative importance of the SCN or waste Stretford solution chemicals to such toxicity and develop better means for its handling and/or materials recovery within the wastewater treatment plant area.

II. Compliance with Contract Requirements

To the best knowledge of the principal investigator, all contractual requirements have or are being met. The P.I. has devoted somewhat more than the originally anticipated 6% of time to this research effort to date. However, this will not effect overall contractual support levels.

A paper was accepted to be presented at the 11th Mid-Atlantic Industrial Wastes Conference, on the subject of this research. The narrative of this DOE Progress Report is essentially that which will be published in the Mid-Atlantic Conference proceedings, and summarizes the work to date.

Narrative

INTRODUCTION

Effluents from coking, coal gasification, and other coal carbonization processes, often contain high levels of polynuclear aromatic hydrocarbons (PAH), phenolics, thiocyanates, free and fixed ammonia, cyanides, sulfates, and alkalinity. Chemical analysis of such effluents varies from process to process due to differing conditions of coal carbonization, gas scrubbing temperatures, and type of coal feedstock used.

In a coal gasification facility, ground coal which may be pretreated to destroy its agglomerating properties, is fed to a gasifier where it reacts with steam and oxygen. Bed temperatures and product gas composition may be varied within limits by the steam-to-coal and oxygen-to-coal ratios employed. In fixed bed and some fluidized bed gasifiers, much of the coal carbon is converted to CO, CO₂, and CH₄, however, a small fraction amounting to 4% to 6% of the feed carbon appears as liquid effluent tars and potential water pollutants from the scrubbed product gas (4).

Coal sulfur is converted to sulfide and thiocyanate (SCN), and coal nitrogen is converted mainly to ammonia. In this respect, the qualitative nature of effluent from fixed bed coal gasification processes is somewhat similar to effluents found from coking and other coal carbonization processes.

Table I (4) presents effluent production data for four different coal gasification processes as a function of coal feed type on a pound produced per pound coal gasified-moisture and ash free (MAF) basis. As can be seen from this table, the quantity of SCN produced per ton of coal gasified can vary from about 0.07 to about 2.5 lb SCN/ton coal MAF. The quantity of wastewater production is a strong function of degree of steam decomposition in the gasifier, and moisture content of coal, and thus is highly process and site dependent. Using Table I, if we assume that about 1 lb. of wastewater is produced per pound of coal (MAF) gasified, the expected thiocyanate concentration in the effluent will range from 35 to about 1250 mg/L.

Research has been underway at the University of Pittsburgh and at the DOE-Pittsburgh Energy Technology Center (5,6,7) to investigate certain key aspects of control technology development associated with coal conversion facilities. The purpose of this paper is to report on some research effort involving the biodegradation of thiocyanate (SCN) as found in some coal conversion and coke plant wastewaters.

PERTINENT LITERATURE

Kostenbader and Flecksteiner (8) investigated the biological oxidation of coke plant "weak ammonia liquor". The maximum thiocyanate loading oxidized in their activated sludge units was 4.8 lb/day-100 cu ft. aeration volume, with oxidation efficiencies ranging from less than 10% to greater than 99%. No explainable reason could be construed for such variations.

Table 1. - Normalized Production of Gasifier Wastewater Pollutants (lb/ton of coal (MAF) +
coefficient of variation if available) After Ref: #4

Parameter	SYNTHANE			LURGI	GFETC		HYGAS
	Montana Rosebud	Illinois #6	N.Dakota Lignite	Montana Rosebud	Lignite 200 psi	Lignite 400 psi	Lignite Run #37
BOD	27.1 $\pm$ 34%			66.5	7		
TOC	22.1 $\pm$ 69%	21.1 $\pm$ 23%	40.7 $\pm$ 24%		13.9	8.3	39.1
COD	55.5 $\pm$ 64%	64.2 $\pm$ 12%	70.6 $\pm$ 33%	103			
PHENOL	8.72 $\pm$ 79%	9.12 $\pm$ 22%	10.8 $\pm$ 36%	21.8		6.8	11.4
OIL & TAR	1.77 $\pm$ 44%	1.96 $\pm$ 34%		3.2	2.8	0.78	
ACETONE SOL. ^{a/}	1.98 $\pm$ 62%	2.26 $\pm$ 36%					
THIOCYANATE	0.067 $\pm$ 105%	0.67 $\pm$ 40%	0.053 $\pm$ 71%	0.08			2.5
CYANIDE ($\times 10^{-4}$)	2 $\pm$ 225%	7.8 $\pm$ 89%	2.1 $\pm$ 110%	200			0.287
H ₂ S	0.033 $\pm$ 95%			0.57			
TOTAL SULFUR	0.449 $\pm$ 22%			1.31			0.2
FREE + FIXED NH ₃	14.0 $\pm$ 29%			72.1	6.6	6.6	13.1
ALKALINITY	3.95 $\pm$ 33%			219	13.3	12.1	
TOTAL TAR + OIL PRODUCTION ^{b/}	30.4 $\pm$ 83%	77.6 $\pm$ 50%		210	70.1	55.5	
WASTEWATER PRODUCTION	2740 $\pm$ 46%	3920 $\pm$ 19%	3300 $\pm$ 42%	2976	916	736	

^{a/} Acetone Soluble Tars: A measure of high molecular weight organics precipitated from pretreated gasifier water by pH depression, an analytical technique developed at PERC

^{b/} Measured prior to settling and hence is not part of the wastewater.

Cousins and Mindler (9) demonstrated that cyanide and thiocyanate oxidation was operationally inconsistent with ammonia concentrations of 1250 mg/L. With levels of ammonia of 100 mg/L or less, thiocyanate destruction was complete with concurrent reduction in cyanide level.

Barker and Thompson (10) report that thiocyanate is only partially removed at low organic loadings of waste from a gas cleaning and by-product recovery system. Residual thiocyanate in the effluent from the carbonaceous reactor was a major contributor to COD in the plant effluent.

In a report by the British Coke Research Association (11), it was observed that thiocyanate concentrations above 2200 mg/L could not be treated at a detention time of 30 hours. Up to about 600 mg/L there is a straight forward relationship between influent thiocyanate concentration and retention time for a removal to a residual of 2 mg/L. No kinetics, however, were quantified for thiocyanate removal in this research effort.

Neufeld and Valiknac (12,13) presented experimental data quantifying the toxic inhibition by low levels of thiocyanate to phenol bio-oxidation. Based on their conclusions, it appears that as the ability of the chemist to measure sub-ppm levels of phenol improves and becomes routine, difficulties in the maintenance of pipeline discharge standard for phenol will become more apparent in thiocyanate laden wastewaters.

Biological processes may be designed for the sequential removal of both phenol and thiocyanate. In order for this to be effective, the design of the system should be based on the biokinetics of thiocyanate, since steel industry practice indicates that thiocyanate degradation occurs after phenol

degradation. In lieu of a one stage system that is often the industry standard, it may be more practical from a kinetic viewpoint to design a series of linked bio-reactors, the first for phenolics, the second for thiocyanates, and perhaps a third for ammonia reduction. In this manner, each sub-system may be operated at pH's and sludge ages consistent with the needs of the specific biological population utilized. Prior to implementing this approach however, a site specific economic systems analysis must be done and compared with judgement to the historical operational instability data for existing one stage systems.

Based on research conducted to date, it appears that the questions of phenolic removal, thiocyanate removal, and ammonia removal, are parts of one overall interlocked biochemical system. Thiocyanate levels inhibit phenol degradation biokinetics, phenol inhibits ammonia removal (nitrification) bio-kinetics (14), thiocyanate biodegradation yields ammonia as an end product, and high levels of un-ionized ammonia (a function of total ammonia and pH) tend to inhibit nitrification biokinetics (14,15). Despite the relatively complicated biochemistry, designed and operated biological processes are the most pragmatic approach to the treatment of coal conversion and steel industry wastewaters. Accordingly, the overall goal of our research program is to better understand and quantify the fundamental kinetic relationships relative to the environmental chemical and environmental process considerations that are necessary for the proper flow sheet design and operation of industrial wastewater treatment facilities.

The specific goal of this particular research effort is to develop a kinetic expression and material balance for nitrogen and sulfur for the biological oxidation of aqueous thio-

cyanates, as found in some coal conversion and steel industry wastewaters.

BIOKINETIC CONSIDERATIONS

One key to utilizing any biological process for industrial purposes is understanding the applicable biokinetics. Many substances act as nutrients at low concentration levels, and serve as toxic inhibitors at higher levels. Based on this research, thiocyanate is one such substance.

Mathematically, a relationship for substrate inhibition may be written as:

$$v = \frac{V_{\max}}{\left[1 + \frac{K_m}{S} + \left(\frac{S}{K_i}\right)^n\right]} \quad (1)$$

As K_i approaches infinity, equation 1 approaches the classical Michaelis-Menton kinetics. Figure 1 is a conceptual plot which compares a classical Michaelis-Menton kinetics with the substrate inhibition model of equation 1. Figure 2 illustrates the inverse of equation 1 as:

$$1/v = 1/V_{\max} + (K_m/V_{\max}) (1/S) + (S^n/K_i^n V_{\max}) \quad (2)$$

The curvature of Figure 2 at low S^{-1} values (high substrate levels) is due to the inhibition term of equation (1).

The values of K_m and $V_{\max}$ can usually be determined in accord with the Lineweaver-Burke plot by considering low substrate levels only. Values of K_i and n are best fit by a numerical and graphical procedure.

SUBSTRATE INHIBITION FUNCTION

Figure 1

INVERSE RELATIONSHIP OF SUBSTRATE
INHIBITION

Figure 2

THIOCYANATE BIOCHEMISTRY

Based on laboratory observations coupled with data presented in the literature, the following equations best represent the biochemical degradation of aqueous thiocyanates (SCN).

Equation 3 indicates sulfate as an end product of thiocyanate degradation, a result which as shown below agrees with the literature, and is also observed in our biological reactors. In accord with this equation, a coal conversion waste stream of about 200 mg/L SCN would contain an additional 331 mg/L additional sulfate and an additional 59 mg/L ammonia after aerobic thiocyanate biodegradation.

Equation 4 shows sulfide as a byproduct of thiocyanate degradation. Since an abiotic solution of thiocyanate is stable over time, formation of sulfide via equation 4 is biologically mediated. It has been observed during the course of this research that if thiocyanate laden sludge is allowed to settle for a few minutes with no air sparging through the system, upon resumption of aeration, unpleasant hydrogen sulfide odors rapidly permeate the laboratory until air stripping totally removes the biologically formed H_2S from solution.

Equation 5 indicates the formation of free sulfur with concurrent rise in pH. Free sulfur has not been visually noted in our reactors, nor has the tendency for rise in pH during the course of aeration. Thus, equation 5 does not appear to occur to any great extent in the experimental system. It is possible, however, that equation 5 may be kinetically favored over equation 3 in systems where the level of dissolved oxygen is limited.

Experimental Procedure

Four fill and draw semi-continuous reactors were maintained during the course of this experiment. Two reactors had a volume of 4 liters with working volume of 3.5 liters, and two reactors had a volume of 15 liters with working volume of 8 liters. Each semi-continuous reactor was maintained with hydraulic detention time of 2 days with sludge age being varied from 5 days to 15 days. Sludge ages were established by wasting a specific volume of mixed liquor suspended solids daily. After wasting, the air was shut off, and sludge was allowed to settle. After settling, the appropriate volume of supernate was removed and replaced with nutrient feed phosphate buffer, and tap water. The pH was maintained at 7 or 8, as required. A complete mix was maintained in each reactor via air stones in the smaller reactor, and by both air stones and electronic mixers in the larger reactors. Dye washout curves were established prior to the reactors being put into service to verify complete mix conditions.

The biological organisms used in this study were developed with SCN as the sole carbon source over a period of time of

6 months prior to the collection of useful data. The initial seed organisms came from a biological wastewater treatment facility treating coke plant wastewaters.

Figure 3 is a plot of the fraction of the sludge considered "volatile" [combustible at 550°C] as a function of sludge age. Typical laboratory sludges grown on synthetic soluble media often attain 85% volatile matter. This figure is consistent with lab data for other systems, and shown that the level of volatility decreases with sludge age as may be expected due to mineralization of sludges at higher sludge ages.

Figure 4 is a kinetic plot of specific utilization of thiocyanate [$\#SCN/\#VSS\text{-hr}$] as a function of thiocyanate in solution. In accord with classical kinetic theory, the specific utilization rate rises with increasing substrate level to a maximum. However, at levels of SCN in excess of about 550 mg/L, the rate of specific utilization begins to decrease in accord with substrate inhibition theory presented on equation (1) and Figure 2.

In accord with the approach indicated in Figure 2, values of $V_{\max}$, K_m , K_i and n were obtained for the thiocyanate system. Figure 4 compares data points with a calculated curve of best fit for the biokinetics of thiocyanate utilization. The equation of this curve is:

$$v = 0.1 / [1 + (62.5/SCN) + (SCN/1270)^6] \quad (6)$$

where v = lb SCN utilized/lb VSS-hour

SCN = mg/L in solution

The inverse plot of this relationship used for the evaluation of $V_{\max}$, and K_m is shown on Figure 5.

Figure 3

Figure 4

Figure 5

From material balance consideration over a long term, it was found that a representative yield coefficient (Y) for thiocyanate degrading organisms was about 0.127 lb VSS/lb SCN. Using this value with a representative endogenous decay coefficient of 0.01 day^{-1} , an operational plot of sludge age vs. effluent thiocyanate level was made, as shown on Figure 5 in accord with the equation:

$$\frac{1}{\theta} = \frac{0.127(24) (0.1)}{[1 + (62.5/\text{SCN}) + (\text{SCN}/1270)^6] + 0.01} \quad (7)$$

From Figure 6 it appears that the thiocyanate bio-oxidation process is unstable at sludge ages of four days or less. From the appearance of figure 6, application of a sludge age safety factor of 2 would result in operation in a relatively flat portion of the curve and thus indicate a more stable operation.

Nitrogen and Sulfur Balance

It has been shown (6) that ammonia is a by-product of thiocyanate biodegradation. One measure of closure of a nitrogen balance is to monitor both thiocyanate-nitrogen and ammonia-nitrogen during the course of SCN biodegradation. Previous work (6) has shown that nitrite-nitrogen and nitrate-nitrogen are negligible as compared to effluent ammonia-nitrogen level. Figure 7 is a plot of percent nitrogen accounted for by ammonia analysis at various sludge ages. Deviations from 100% closure on the nitrogen material balance are attributed to air stripping of ammonia from the aerobic completely mixed reactor and not due to the formation of nitrite and nitrate. No explanation is evident for the apparent minima in the curve, and work

Figure 6

SCN vs. SLUDGE AGE

Figure 7 Nitrogen Balance

underway shall verify if this minima can be reproduced or is simply an artifact of data. Figure 6 indicates however that 89% to 106% of the SCN was accounted for.

It has also been shown (8) that sulfate is the principle by-product of sulfur in the thiocyanate complex after aerobic biodegradation.

Figure 8 illustrates apparent closure of the material balance for sulfur when sulfate alone is monitored as a measure of sludge age. It should be noted that influent sulfur was derived solely from the sulfur in the thiocyanate complex used as the micro-organism food source. At no time during the course of aerobic degradation did "nose" testing for H_2S indicate its presence. It should be noted, however, that the data shows that 90% to 97% of influent sulfur is accounted for in the conversion from thiocyanate to sulfate. The environmental significance of discharged sulfate is small. Sulfate would be required to be removed, however, if a water recirculation system or cooling tower system were utilized in a coal conversion facility and treated effluent was used as water make-up. Sulfate precipitation of calcium and other metals may represent a limiting factor in the design of such water re-use systems.

SLUDGE SETTLING PROPERTIES

Table 2 presents a summary of sludge settling rates and sludge volume index data. Sludge volume indices of less than 100 cc/g are often considered to represent "good settling" sludge.

Figure 8 Sulfur Balance

In general, supernate suspended solids upon 30 minutes of settling were negligible, indicating no apparent sludge deflocculation. It appears that the nature of the thiocyanate degrading sludge is such that no problems are anticipated in the design of sludge clarification facilities. It should be noted, however, that this research deals with a relatively pure culture, and translation of results to the field should be done with caution.

Table 2

THIOCYANATE SLUDGE SETTLING CHARACTERISTICS

Sludge Age (days)	Settling Velocity (ft/hr)	Sludge Volume Index (cc/g)
15 days [pH = 7.0]	6.91	30.9
5 days [pH = 7.0]	13.79	32.9
15 days [pH = 8.0]	13.8	24.2
10 days [pH = 8.0]	6.48	26.2

CONCLUSIONS

1. Thiocyanates (SCN) are seen as a pollutional parameter of importance in coal conversion wastewaters influencing phenolic biodegradation and servicing as an indicator parameter for biological process control.
2. SCN assumes increased relative importance in the waste-treatment train with the incorporation of solvent extraction for phenol recovery and/or a Stretford system for S recovery from H_2S in the hot gas.
3. Quantification of batch kinetics for SCN destruction have been developed. These kinetics follow a substrate inhibition pattern.
4. SCN degradation leads to residual $SO_4^{=}$ and NH_4^{+} in the liquid effluent. While low level discharges of $SO_4^{=}$ are not expected to pose severe environmental difficulties, low level discharges of NH_4^{+} may result in conflicts with State pollution control agencies. As an example, for the Steel Industry, BACT, [Best Available Control Technology] pipeline effluent limitations for total ammonia are expected to be 10 mg/L.
5. Thiocyanate biokinetics are quantified; analysis indicates a maxima in SCN specific removal rates at about 550 mg/L with decreasing rates at increasing SCN levels. A "substrate inhibition" model has been developed to best predict SCN biokinetics.

REFERENCES

1. Pearch, A. S., Punt, S. E., "Biological Treatment of Liquid Toxic Wastes", Effluent and Water Treatment Journal (England) pp. 32-39, January, 1975
2. Kleeberg, U., (Gottfried Bischoff GmbH & Co. Kg) "Removal of Hydrogen Sulfide from Gases Using the Stretford Process", Prepared for the Fifth International Conference on Coal Gasification, Liquefaction, and Conversion to Electricity, August 8-10, 1978, Pittsburgh, PA.
3. Dravo Corporation, "Handbook of Gasifiers and Gas Treatment Systems", Final Report Prepared for the U.S. ERDA Contract #E (49-18) 1772, available as FE-1772-11, February, 1976
4. Neufeld, R. D., Drummond, C. J., Johnson, G. E., "Biokinetics of Activated Sludge Treatment of SYNTHANE Fluidized Bed Gasification Wastewaters", Preprints of the ACS Fuels Chemistry Division, Vol. 23, No. 2, pp. 175-186, March, 1978
5. Johnson, G. E., Neufeld, R. D., Drummond, C. J., Strakey, J. P., Haynes, W. P., Mack, J. D., Valiknac, T. J., "Treatability Studies of Condensate Water from SYNTHANE Coal Gasification", DOE/PERC/RI-77/13, Nov., 1977
6. Neufeld, R. D., Hill, A. J., Adekoya, D., "Preliminary Sulfur and Nitrogen Balance for the Biological Degradation of Thiocyanate", Progress Report under contract #EY-77-S-02-4502.A1 October, 1978
7. Drummond, C. J., Johnson, G. E., Neufeld, R. D., Haynes, W. P., "Biochemical Oxidation of Coal Conversion Wastewaters", presented at the Wastewater from Fuel Conversion Session, 87th National AIChE Meeting, Boston, August, 1979
8. Kostenbader, P. D., Flecksteiner, J. W., "Biological Oxidation of Coke Plant Weak Ammonia Liquor", J.W.P.C.F. 41 pp. 199-207, (1969)
9. Cousins, W. G., Mindler, A. B., "Tertiary Treatment of Weak Ammonia Liquor", J.W.P.C.F. 44, 4, pp 607-618 (1972)

REFERENCES (con't)

10. Barker, J. E., Thompson, R. J., "Biological Removal of Carbon and Nitrogen Compounds from Coke Plant Wastes", EPA-R2-73-167, April, 1973
11. British Coke Research Association, "The Biological Treatment of Coke Oven Effluents: Laboratory and Pilot-Plant Studies", Coke Research Report 43, November, 1966
12. Neufeld, R. D., Valiknac, T., "Inhibition of Phenol Biodegradation by Low Levels of Thiocyanate", Paper accepted for publication, Jour. Water Pollution Control Federation
13. Valiknac, T., Neufeld, R. D., "Thiocyanate Toxic Inhibition to Phenol Bio-oxidation", Proc. of the 33rd Purdue Industrial Waste Conf., May, 1978, W. Lafayette, Ind.
14. Neufeld, R. D., Hill, A. J., Adekoya, D. O., "Influence of Un-Ionized Ammonia and Phenol on Nitrification Biokinetics for Steel Industry Wastewater", Prepared for, and available from the American Iron and Steel Institute, Project #78-395, Feb., 1979
15. Hill, A. J., Neufeld, R. D., "Influence of Un-Ionized Ammonia and Inorganic Carbon on Biological Nitrification", Proceedings of the 34th Purdue Industrial Waste Conf., May, 1979, W. Lafayette, Ind.