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Development of an Arsenic Measurement Method on a Gold Roasting Operation

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DEVELOPMENT OF AN ARSENIC MEASUREMENT METHOD
ON A GOLD ROASTING OPERATION

by

Ray Capowski

Northwest Region
Environmental Protection Service
Environment Canada

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ABSTRACT

Source tests carried out at the roaster stack of Giant Yellowknife Mines Ltd. were undertaken to verify the applicability of "Standard Reference Methods for Source Testing: Measurement of Emissions of Particulates from Stationary Sources" (3) to the controlled release of arsenic from the roaster off-gas dust control system. Tests for sulphur dioxide were also conducted.

A brief description of the ore roasting process and off-gas dust control system is provided. The stack sampling and analytical methods are also summarized.

It is recommended that further testing for arsenic be performed on a controlled source to validate recommended changes to the source testing code.

RÉSUMÉ

Des essais à la source ont été faits à la cheminée du four à griller de la société Giant Yellowknife Mines Ltd. sur le débit d'arsenic du système réglant le dégagement de poussières. On a également fait des essais pour déceler les émanations d'anhydride sulfureux. Cette entreprise avait pour but de vérifier l'application des techniques décrites dans Méthodes de référence normalisées en vue d'essais aux sources: mesure des émissions de particules provenant de sources fixes.

Le rapport comprend une description sommaire du procédé de grillage du minerai ainsi que du système réglant le dégagement de poussières. Les méthodes de prélèvement et d'analyse des substances rejetées par la cheminée sont également résumées.

On recommande de faire d'autres essais pour déterminer de façon plus certaine la teneur en arsenic des substances se dégagent d'une source réglée afin de justifier les changements qu'on recommande d'apporter au manuel mentionné ci-dessus.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	iv
LIST OF TABLES	v
1 INTRODUCTION	1
2 CONCLUSIONS AND RECOMMENDATIONS	1
3 PROCESS DESCRIPTION	2
3.1 Gold Recovery	2
4 EMISSION CONTROL	3
4.1 Cottrell Plant	3
4.2 Baghouse Plant	6
5 TEST METHODS	9
5.1 Particulates and Moisture	9
5.2 Dry Gas Analysis	9
5.3 Sulphur Dioxide	11
6 STACK TESTS	11
7 SAMPLE RECOVERY	13
8 SAMPLE ANALYSIS	13
8.1 Nozzle-Probe and Filter Holder Washings	13
8.2 Glass Fibre-Filter	14
8.3 Impinger	14
8.4 Impinger Washings	14

	<u>Page</u>
9 RESULTS	14
10 DISCUSSION	28
ACKNOWLEDGEMENTS	30
REFERENCES	31
APPENDIX I Particulate Sampling Data	33
APPENDIX II Gaseous SO ₂ Sampling Data	47
APPENDIX III Process Description	51

FIGURE	LIST OF FIGURES	PAGE
1	PROCESS FLOW DIAGRAM GIANT YELLOWKNIFE MINES LTD.	4
2	GIANT YELLOWKNIFE MINES GAS AND DUST TREATMENT	7
3	PARTICULATE SAMPLING TRAIN	10
4	CROSS SECTION OF STACK SHOWING TRAVERSE POINTS	12
5	PLOT OF PITOT-TUBE CALIBRATION FACTORS AS A FUNCTION OF VELOCITY MEASURED	17
6a	STACK GAS VELOCITY DISTRIBUTION E-W TRAVERSE	18
6b	STACK GAS VELOCITY DISTRIBUTION N-S TRAVERSE	19
7	SEMI-LOG PLOT OF THE EQUILIBRIUM VAPOUR CON- CENTRATIONS OF ARSENIC AS A FUNCTION OF TEMPERATURE	29

LIST OF TABLES

TABLE		PAGE
1	TYPICAL PRODUCT ASSAYS	5
2	ROASTER OPERATING CONDITIONS	5
3	BAGHOUSE DUST ANALYSIS (APPROX.)	8
4	STACK TEST RESULTS	15
5	STACK GAS ANALYSIS AND MOLECULAR WEIGHT	15
6	PARTICULATE WEIGHTS - TOTAL	20
7	PARTICULATE ANALYSIS - ARSENIC	22
8	PERCENTAGE OF ARSENIC, IRON AND ANTIMONY IN WASHINGS FROM NOZZLE, PROBE AND FRONT HALF OF FILTER HOLDER	23
9	FILTER PARTICULATE - ARSENIC, IRON, AND ANTIMONY PERCENTAGE	24
10	IMPINGER CATCH - ARSENIC, IRON AND ANTIMONY PERCENTAGE	25
11	SUMMARY OF SULPHUR DIOXIDE EMISSIONS	27

1 INTRODUCTION

To aid in the development of an arsenic test method, a stack sampling program was undertaken at Giant Yellowknife Mines Ltd. in August 1975. The Environmental Protection Service in Edmonton, with support from Surveillance Division in Ottawa and the Yellowknife District Office, attempted to validate a proposed stack sampling method for arsenic, as well as gather pertinent results to be utilized in assessing the magnitude and scope of the environmental concerns in Yellowknife. Particulate emissions were determined using the federal standard reference method for source testing at stationary sources (3). The sampling program included:

- a) utilization of both 2% (weight by volume) sodium hydroxide (NaOH) solution and water in the bubbler train,
- b) maintenance of the filter compartment at a temperature of 190° - 200°F,
- c) washing probe, nozzles and all connecting glassware with 2% NaOH,
- d) inclusion of the weight of arsenic collected in the back half of the collection train in the determination of the total weight of arsenic collected.

Sampling for sulphur dioxide was also conducted.

2 CONCLUSIONS AND RECOMMENDATIONS

During the test period, the average grain loading of arsenic was 0.033 gr/scf. The average emission rate was calculated to be 167 lb of arsenic per day, with a range of 127 to 238 lb per day. Approximately 87% of the total arsenic collected was contained on the glass fibre filter as a particulate, and averaged 37% arsenic upon subsequent analysis.

Sulphur dioxide emissions were measured at 1.42% by volume in the exiting flue gas. The emission rate was calculated to be 41.5 tons per day.

Recommendations for future surveys or the application of test

methods for this element include:

- a) the running of comparative tests to determine whether the filter should be maintained at or below 200°F - the temperature specified in the test code (3),
- b) the washing of all inner surfaces of sampling equipment with water, followed by an acetone rinse,
- c) the use of water as the scrubbing media in the impingers,
- d) further research to determine whether the weight of arsenic collected in the impingers should be included in the calculation of total weight,
- e) the analysis of each impinger to evaluate the efficiency of collection in this portion of the sampling train,
- f) the evaporation of the contents of the impingers and impinger washings to dryness at below 200°F.

3 PROCESS DESCRIPTION

3.1 Gold Recovery

In the recovery of gold from ore, various physical and chemical separation processes are employed. After crushing and milling, the ore enters the floatation circuit at 40% solids and passes through two, 12-cell parallel banks of #24 DR cells. Final flotation tailings report to the backfill plant and all concentrate is united to form the roaster feed.

Bulk flotation not only concentrates gold, but must, because of the type of ore, concentrate the arsenic and antimony content. To overcome this objectionable association in the concentrate and to free gold for cyanidation, physical and chemical breakdown is necessary prior to leaching. This is accomplished in a two-stage Fluo Solids roaster. The purpose of roasting is to produce porous particles by volatilization of arsenic, antimony, and sulphur, thereby exposing gold. By eliminating a high percentage of arsenic and by controlling conditions of the roast to preclude formation of arsenates and magnetite, calcine is made amenable to cyanidation.

Roasted calcine product undergoes a series of thickening and grinding operations to further expose the gold in preparation for the gold extraction process. Cyanide extraction is carried out on the repulped calcine in several stages of agitation, thickening and filtering.

The final step in the extraction of gold is the precipitation circuit. In the precipitation circuit zinc dust is added to the pregnant cyanide solution to precipitate the gold. The precipitated gold is then recovered by forcing the solution through a press.

The process is shown schematically in Figure 1. Tables 1 and 2 give typical product assays and roaster operating conditions respectively.

4 EMISSION CONTROL

4.1 Cottrell Plant

The dust-laden roaster gases leaving the second stage reactor enter two Ducon cyclones in series. Each cyclone discharges dust to an integral quench tank. Leaving the cyclones at approximately 840°F, the remaining dust and gases are conducted by flue to two hot cottrell units operating in parallel. While traversing the flue between the roaster and Cottrell buildings, gases are air-tempered to 700°F before entering the electrostatic precipitators.

The precipitators are two identical type K, rod-curtain Cottrells; each Cottrell has two units in parallel, and each unit is made up of two sections in series. Each section is composed of 882, 1/8 in. dia., collecting electrodes and 272, 3/16 in. square twisted discharge electrodes. Collecting electrodes are arranged to form 18 curtains, 8 ft. long and 12 ft. high with an 8 in. duct between curtains. Discharge electrodes form 17 curtains and sit in the 8 in. ducts.

Time-controlled rapping hammers strike collecting and discharge electrode frames to dislodge dust from the electrodes. Collected in V-shaped hoppers immediately below the Cottrells, dust is screw-conveyed to quench tanks.

Distribution and gas flow through the units is controlled by multi-vane dampers at the inlet and outlet end of each unit. At present, only two of the four units operate, while the remaining two are held in reserve. When severe shorts or other difficulties arise in an on-stream unit, a standby unit is cut in until repairs are complete. Each unit receives a major overhaul every two years.

The Cottrell dust arsenic and antimony content are in the 3.0% and 1.5% range, respectively. Any lowering of collection efficiency is immediately apparent in assays of baghouse dust.

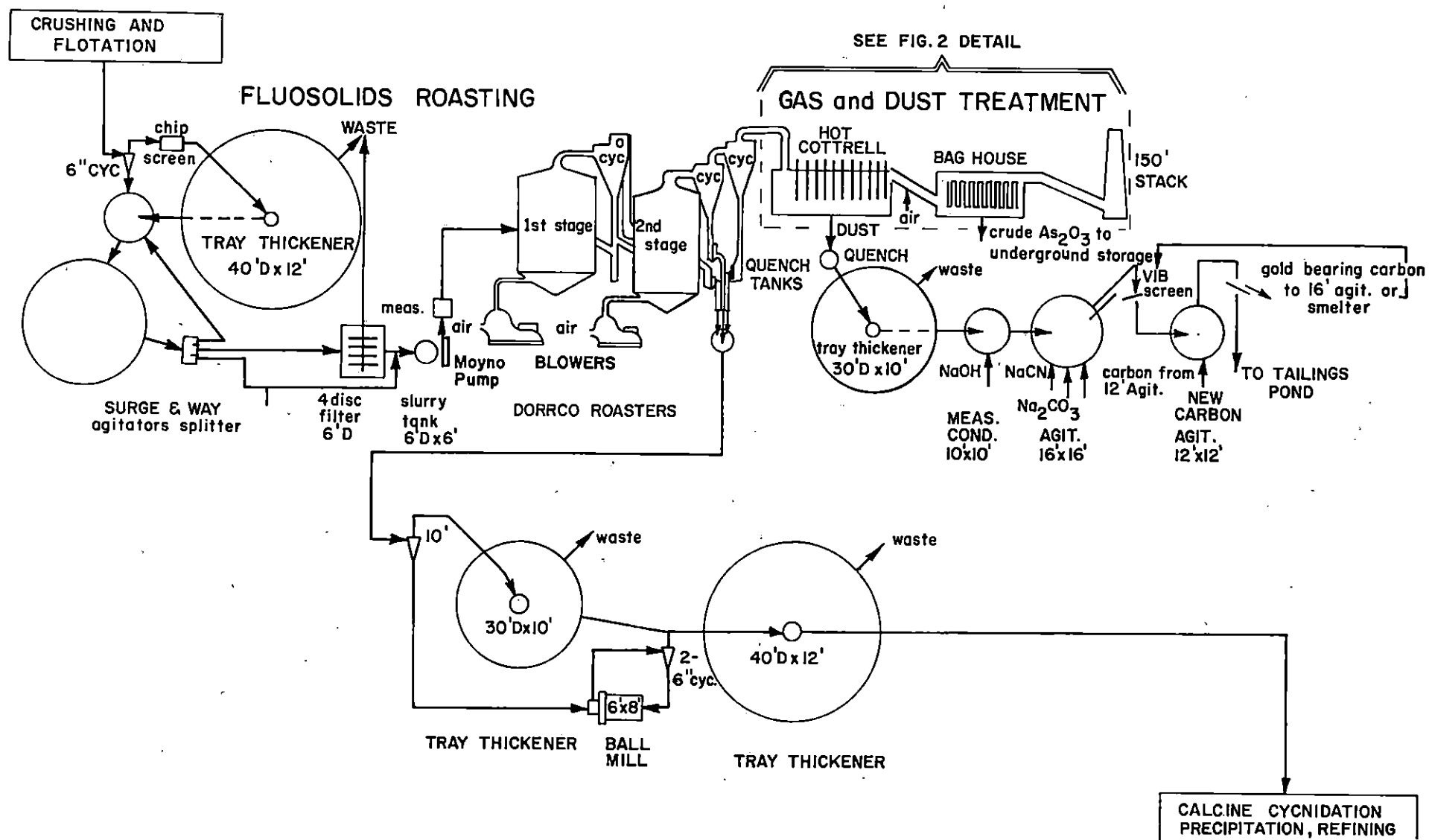


FIGURE 1 PROCESS FLOW DIAGRAM GIANT YELLOWKNIFE MINES LTD.

TABLE 1
TYPICAL PRODUCT ASSAYS (APPROXIMATE)

	Percent (%) By Weight			
	Iron	Sulphur	Arsenic	Antimony
Flotation concentrate	21.7	18.9	8.6	0.7
Roaster feed (170 tons/day)	21.2	19.0	8.5	0.7
Roaster calcine (130 tons/day)	27.3	3.3	1.2	0.5
Cottrell dust (11 tons/day)	-	2.5-3.0	5-6	6-7

TABLE 2
ROASTER OPERATING CONDITIONS

	First Stage	Second Stage
Bed temperature ($^{\circ}$ F)	925	925
Freeboard temperature ($^{\circ}$ F)	825	865
Airflow (cfm)	3050	950
Spray Water (IG/pm)	1.28	2.22
Winbox pressure (psi)	3.84	3.26

4.2 Baghouse Plant

The Cottrell exit gases are drawn and air tempered by a mixing fan. Dilution air is drawn through a louvre automatically controlled to maintain the inlet temperature at 225°F. At this temperature, the arsenic in the gas passes through its transition temperature, and is collected as solid arsenic trioxide. If for any reason inlet gas temperature rises to 250°F, a thermostat-controlled automatic door in the side of the inlet flue opens, admitting large volumes of room-temperature air.

The baghouse is an eight-compartment No. 30 DRACO type with each compartment containing 300, 5 in. dia. x 10 ft. orlon bags. The design provides a 1.9 cfm per square foot air to cloth ratio. Bag life is approximately two years.

The collected arsenic is dislodged by a timed shaking device into V-shaped hoppers. Screw conveyors move the dust to a Fuller-Kinyon pump which, operating intermittently, conducts it via a 4 in. line to permanently sealed perma-frost stopes underground. Return gas from the stopes re-enters the flue system directly ahead of the baghouse.

A variable-speed, controlled stack fan draws the cleaned gas to a 9 ft. dia. x 150 ft. acid brick stack.

Flue gas velocity and temperature are approximately 8.5 ft/sec. and 190°F, respectively, in the stack.

On the average, 25 tons of baghouse dust and 11.5 tons of cottrell dust are collected daily. The cottrell dust, although not amenable to conventional cyanidation methods because of the arsenic and antimony content, is batch treated by a cyanide leach-carbon strip process.

Table 3 gives a typical baghouse product analysis.

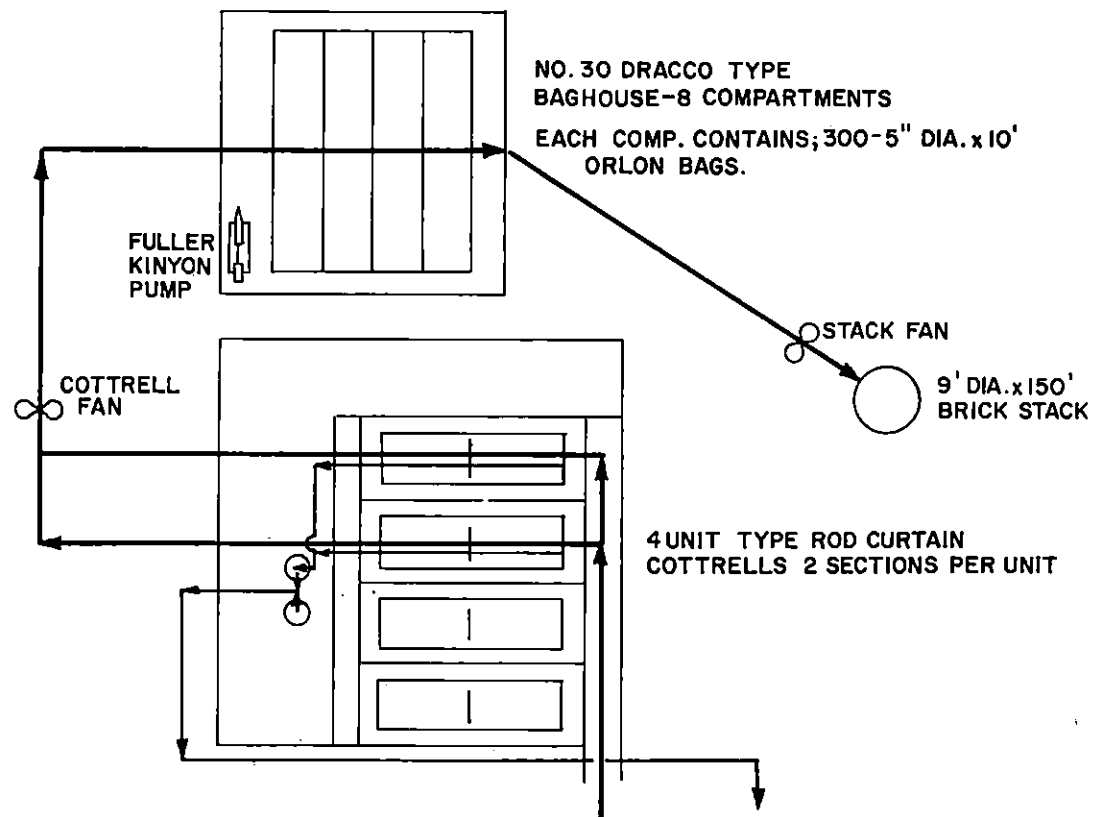


FIGURE 2 GIANT YELLOWKNIFE MINES GAS AND DUST TREATMENT

TABLE 3
BAGHOUSE DUST ANALYSIS (APPROXIMATE)

Element	% By Weight	Oxide	% By Weight
*Arsenic	65.0	As_2O_3	85
Iron	0.8	Fe_2O_3	1.2
Silicon	0.5	SiO_2	1.0
Aluminum	0.3	Al_2O_3	0.5
Magnesium	0.1	MgO	0.2
Calcium	0.1	CaO	0.15
Antimony	0.2	Sb_2O_3	0.30
Selenium	0.45		
Lead	0.02		
Zinc	0.01		
Copper	0.01		
Cadmium	0.001		
Baryllium	0.001		

*Arsenic analyzed as 99+% in oxidation state +3.

5 TEST METHODS

5.1 Particulates and Moisture

Stack gas samples for particulate determination were collected according to Method E of the federal standard reference methods for source testing (3) with modifications to suit this particular source. On test run number 4, the water in the impingers was replaced by a 2% sodium hydroxide solution to check the validity of arsenic vapour solubility in the liquid impinger, back half of the sampling train. During all runs the filter compartment was maintained at an average temperature of $190^{\circ}\text{--}200^{\circ}\text{F}$ instead of the normal 225°F . This was done to prevent volatilization of the collected arsenic from the filter into the liquid impinger portion of the sampling train. The sampling train was modified to continuously control and monitor filter temperature at $200 \pm 5^{\circ}\text{F}$. Lastly, the weight of arsenic condensed in the impingers was included in the calculation of the total arsenic collected. This was done because of the nature of the operation being tested and the absence of a known test method for this particular element.

Instrumentation consisted of a commercially available Research Appliance Company (RAC) sampling train (Figure 3). The train consisted of a 10 ft., heated, stainless steel-lined probe and pitot tube assembly, a filter holder housed in a heated compartment external to the stack, four Greenberg-Smith impingers connected in series, a leak-free pump, a dry gas meter, and other related accessories necessary for isokinetic sampling. The particulate loading was determined both quantitatively and qualitatively. The particulate matter collected on the filters was dried, weighed and subsequently analyzed for arsenic to determine the percent by weight in the total sample. The probe and nozzle washings as well as the impinger contents were examined in the same manner.

The moisture content of the gas stream was determined according to Method E of the federal standard reference method (3) by measuring the condensate in the impingers, converting to an equivalent gaseous volume, and relating this to the total volume sampled.

5.2 Dry Gas Analysis

Gas samples from the stack were removed daily for analysis to determine the molecular weight of the stack gases according to Method C of the federal reference method (3). The components of interest were

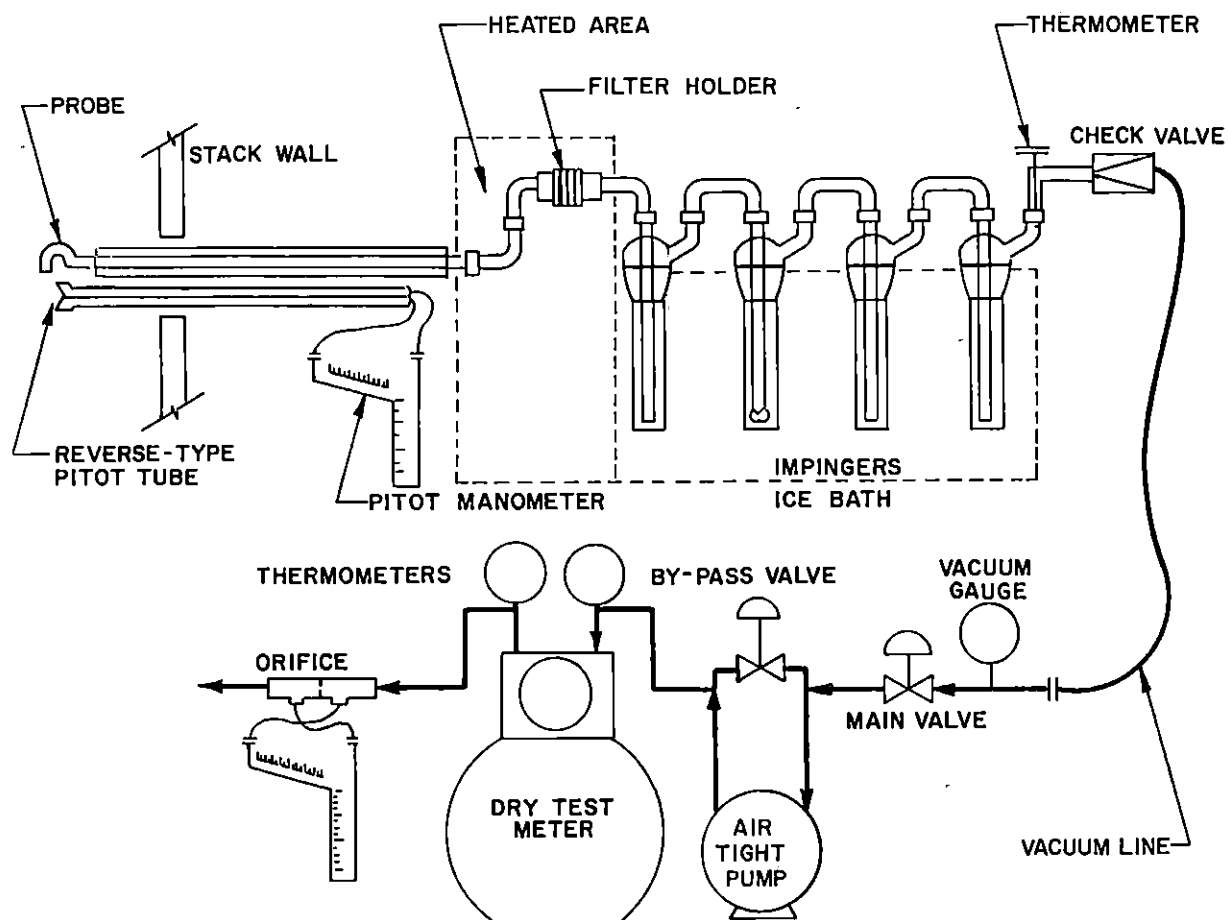


FIGURE 3 PARTICULATE SAMPLING TRAIN

oxygen, carbon dioxide and nitrogen. Samples were removed with a hand aspirator, stored in Mylar bags and analyzed using a portable gas chromatograph.

5.3 Sulphur Dioxide

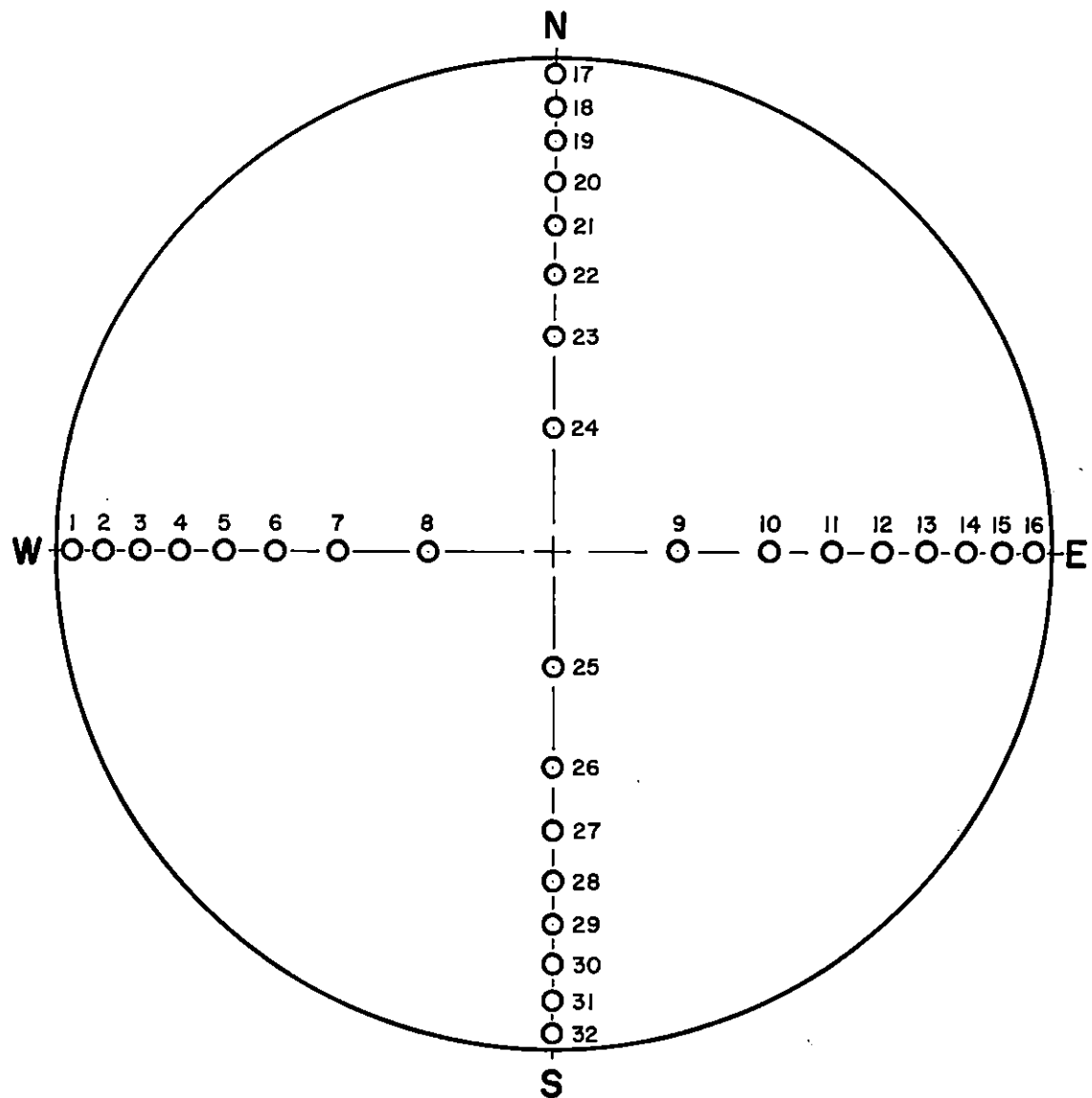
The hydrogen peroxide method (2) of determining sulphur dioxide in stack gas was used. This method involves bubbling a known volume of the gas through a 5% solution of hydrogen peroxide. The sulphur dioxide in the gas is converted to sulphuric acid which increases the acidity of the sampling solution. This increase and hence the concentration of sulphur dioxide is measured by back-titrating an aliquot of the exposed sampling solution with standardized sodium hydroxide. The normality of the sodium hydroxide is determined by titrating against standard 0.10 N sulphuric acid. The 5% hydrogen peroxide sampling solution is prepared by diluting 30% hydrogen peroxide.

Before each run, 125 (\pm 0.5) ml. of hydrogen peroxide sampling solution was measured into each of three standard 500 ml. Greenberg-Smith impingers. An in-stack paper thimble was placed upstream of the impingers to filter all particulate matter in the flue gas stream. A constant sampling flow rate of 0.5 cfm was chosen and maintained throughout the run to obtain a proportional sample.

6 STACK TESTS

Tests were conducted from August 14-19, 1975, from a platform encircling one-half the stack diameter at approximately the 75-ft. level. Access to the stack gas stream was through two ports spaced 90° to one another on the stack diameter. The inner stack diameter was 9 ft. x 0 in. with a 28 in. wall thickness composed of refractory brick and an 8 in. diameter port protruding approximately 12 in. outward from the outer wall. Since this location was felt to be ideal for sampling, a minimum number of 32 traverse points were chosen (Figure 4), 16 on each diameter. Sampling time at each point was 5 min., the minimum required by the code. This provided an overall sampling time of 160 min. All sample recoveries, dry gas analyses, and moisture determinations were conducted in the plant laboratory.

STACK DIAMETER 108.0"



scale 1:20

FIGURE 4 CROSS SECTION OF STACK SHOWING TRAVERSE POINTS

7 SAMPLE RECOVERY

The interior surfaces of the nozzle-probe assembly were washed with 2% sodium hydroxide instead of acetone to dissolve any arsenic vapour or particulate which may have collected in it. The interior surfaces of the filter holder preceding the filter were also washed with 2% sodium hydroxide and added to the nozzle-probe washings. The contents of the three impingers containing absorbing or dissolving fluid were transferred to a second container for analysis. These impingers and all connecting glassware were rinsed with 2% sodium hydroxide instead of distilled water because it was believed that arsenic trioxide may condense along the walls as it cools down.

8 SAMPLE ANALYSIS

8.1 Nozzle-Probe and Filter Holder Washings

The contents of these containers were prepared for both quantitative and qualitative analyses. After measuring the total volume of solution in each container, the sample and control blanks were evaporated to dryness in 250-ml beakers on a steam bath. Samples were quantitatively transferred to tared platinum dishes and further dried at 105°C for 24 hrs.. After cooling in a desiccator for 1/2 hr., sample weights were determined (particulate plus sodium hydroxide). Samples were then rediluted with distilled water, and the resultant basic solution was neutralized to a phenolphthalein endpoint with concentrated hydrochloric acid. To each subsequent sample volume, 20 mls of 2% sodium hydroxide was added and the total volume evaporated down to 25 mls on a steam bath. Digested samples were then quantitatively filtered through Watman #41 filter papers into 50-ml volumetric flasks and diluted to volume. Using an aliquot of this prepared solution, a determination for arsenic was performed using a colorimetric technique developed by Vasak and Sedivec (6). Other heavy metals, namely antimony and iron, were analyzed for in both the soluble and insoluble portions, using an acid (hydrofluoric and nitric) digestion. This was followed by direct aspiration in an atomic absorption unit. Results were reported as micrograms (μg) of element present in the sample.

8.2 Glass Fibre-Filter

The filters and any loose particulate matter were desiccated for 24 h and reweighed for gravimetric determinations. The samples were then transferred to 150-ml beakers and digested with 20 ml of 2% sodium hydroxide. The solution was then filtered through a Watman #41 filter paper into a 100-ml volumetric flask. The colorimetric technique of analysis for arsenic was performed on an aliquot of this solution. Analysis for other heavy metals was performed using acid digestion with direct aspiration in an atomic absorption unit.

8.3 Impinger

The impinger contents were evaporated to dryness on a steam bath. The direct sample was transferred to preweighed platinum dishes and further dried for 24 h in an oven at 105°C. After cooling in a desiccator for 1/2 h, the weights were recorded. Samples were then digested in 20 ml of 2% sodium hydroxide. The solution was then filtered and made up to 50 ml with distilled water washings. Using an aliquot of the prepared solution, a determination for arsenic was performed. The weight of arsenic collected in the wet impingers was added to the nozzle-probe washing and filter weights to obtain a total weight for arsenic. These solutions were analyzed for other heavy metals.

8.4 Impinger Washings

All impingers and connecting glassware were rinsed with 2% sodium hydroxide to dissolve any arsenic adhering to the walls. These washings were separately analyzed in the same manner as the impinger contents.

9 RESULTS

Appendix I contains the test data for each run. Also included is an analysis of the degree of isokineticity achieved during each test and the corresponding emission rates. For ease of comparison, however, the most pertinent information such as total volume sampled, total gas flow, and arsenic particulate emission concentrations and rates are summarized in Table 4. Results have been corrected to a reference pressure and temperature of 29.92 in. Hg and 77°F respectively. The arsenic

TABLE 4 STACK TEST RESULTS

Aug. 1975	Run	Total Volume Sampled (ft ³)	Gas Flow (scf/min)	Percent Isolinetic (%)	Arsenic Emissions	
					(gr/scf)	lb/day
14	1	108.32	24,390	129.56	0.02995	150.31
15	2	96.49	23,780	118.92	0.04873	238.32
16	3	89.73	22,830	114.89	0.03318	155.79
17	4	104.28	25,930	117.83	0.03284	175.14
18	5	102.66	25,400	118.15	0.03009	157.26
19	6	94.37	24,000	115.15	0.02585	127.64
Average			24,390	119.08	0.03344	167.41

TABLE 5 STACK GAS ANALYSIS AND MOLECULAR WEIGHT

Run No.	% CO ₂	%SO ₂ *	%O ₂	%N ₂	M _d **	%H ₂ O	M _s ***
1	0.10	1.40	20.0	78.50	29.32	7.68	28.45
2	0.40	1.60	19.9	78.10	29.83	7.53	28.94
3	0.10	1.15	19.6	79.15	29.47	7.44	28.62
4	0.15	0.85	20.3	78.70	29.37	7.65	28.50
5	0.10	1.40	19.8	78.70	29.31	7.09	28.51
6	0.10	1.15	20.0	78.75	29.23	8.02	28.33

*%SO₂ - Approximate analysis (FYRITE analysis - % CO₂).

**M_d - Stack gas molecular weight, dry (lb/lb mole).

***M_s - Stack gas molecular weight, wet 91b/lb mole).

emission rates include both the front half and back half (impingers) weights.

The isokinetic variation for all tests was between 114% - 129%. When the results of the analysis for isokineticity are examined for each run on a point-to-point basis, it can be seen that the values are consistently higher than desired. Further examination of the data and calculations revealed a significant variance in one parameter, namely the pitot tube calibration factor (C_v), which accounted for this error. S-type pitot tubes suffer from flow eddies and nonuniformities at low velocities because of their larger cross-sectional area. Their limit of sensitivity is approximately 10 fps, precisely at or near the velocities encountered during these tests. Attempts were made to obtain calibration factors in the velocity range of interest but, as one can see from Figure 5, there was a variation in the correction factor of 0.06 (0.73 to 0.79). The degree of accuracy associated with the pitot tube calibrations was limited and as a result the variance could be as high as 0.1. The plot of Figure 5 was used to obtain correction factors for each velocity range of interest. It was felt that this would be more accurate than using an average pitot-tube correction factor for the entire survey. Using a correction factor of 0.83, that normally obtained for S-type pitot tubes, would have brought five of six runs within the allowable isokinetic variation of 90% to 110%.

The results of the analysis for determination of the stack-gas molecular weight are listed in Table 5. A characteristic stack-gas velocity distribution is shown in Figures 6a and 6b.

The results of all gravimetric determinations performed are given in Table 6. Of most significance are the results pertaining to the glass fibre filters because it was on the filters that the significant amounts of arsenic were collected. Weight determinations for the front half washings are reported although a considerable amount of variance was observed in the values. Difficulties were encountered as a result of washing the probe and connecting glassware with 2% sodium hydroxide. To obtain the weights of particulate matter collected, it was necessary to take the samples to complete dryness. Once achieved, background values of 25 to 30 gm of sodium hydroxide crystals remained in the sample. Suit-

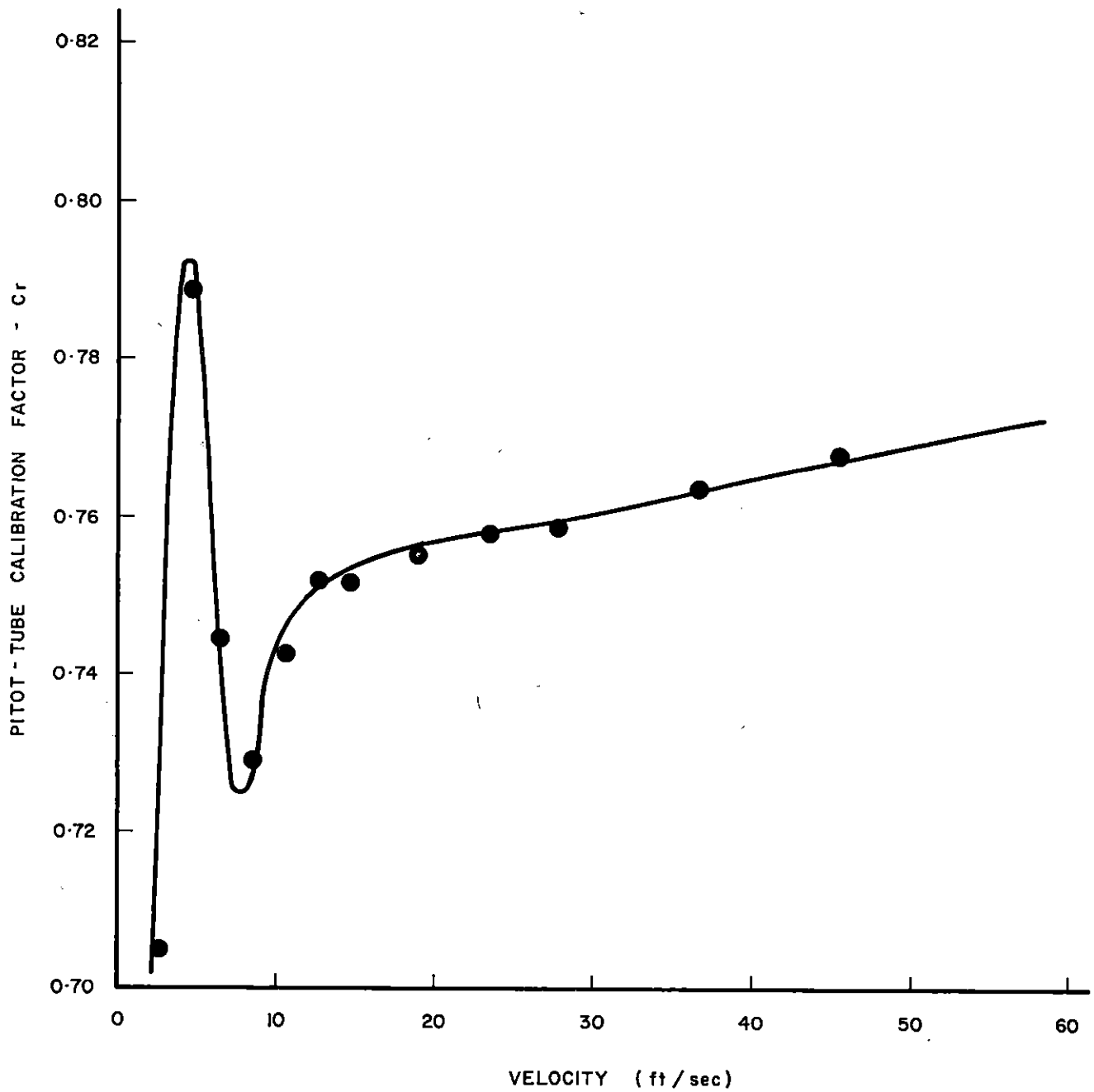


FIGURE 5 - PLOT OF PITOT-TUBE CALIBRATION FACTORS AS A FUNCTION OF VELOCITY MEASURED

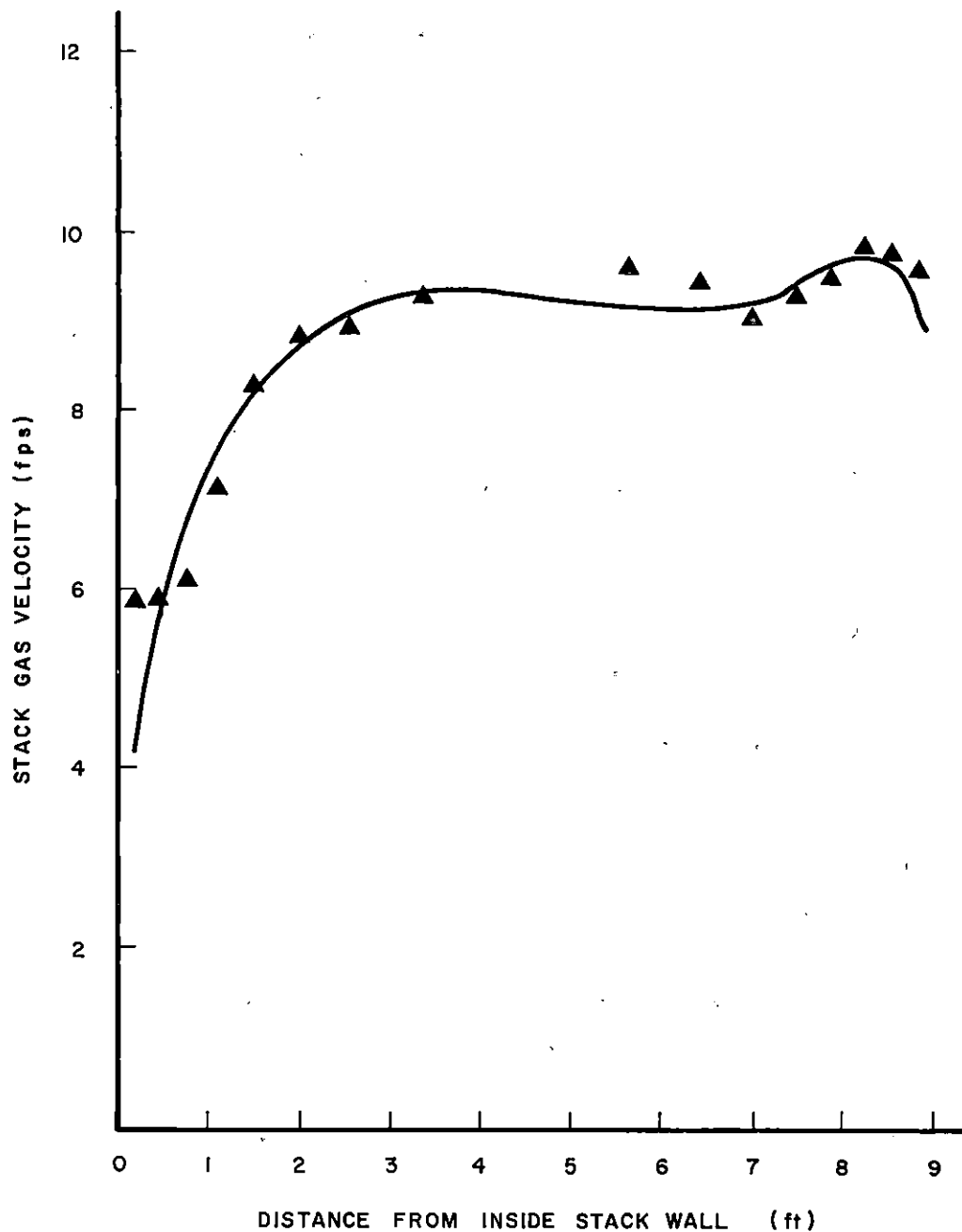


FIGURE 6a - STACK GAS VELOCITY DISTRIBUTION E-W TRAVERSE

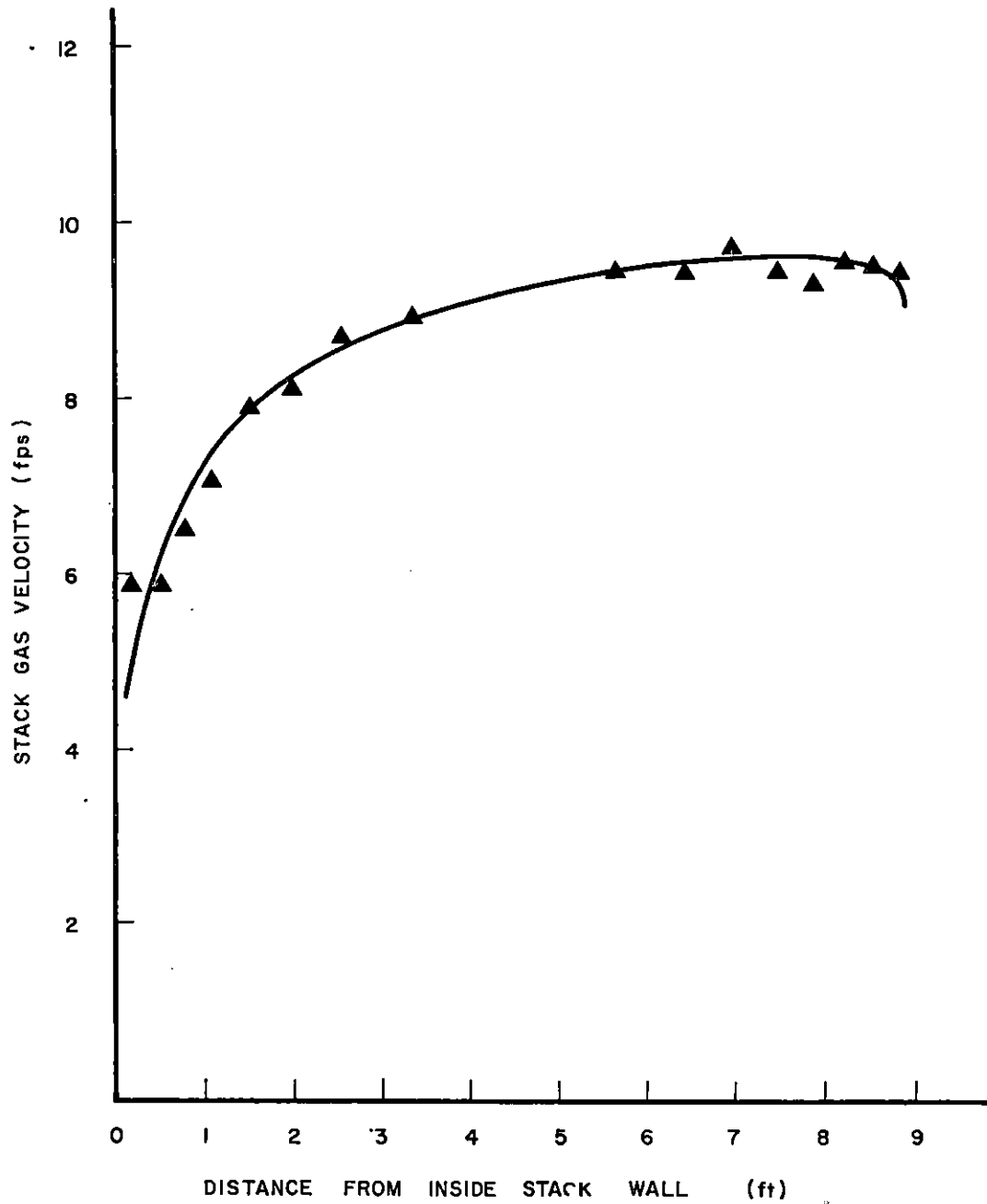


FIGURE 6b - STACK GAS VELOCITY DISTRIBUTION N-S TRAVERSE

TABLE 6 PARTICULATE WEIGHTS - Total

Run No.	Washings from Nozzle, Probe & front half of filter holder (g)	Glass fibre filter (g)	Impinger catch* (g)	Washings from connectors, impingers & back half of filter holder (g)	Total sample weight (excluding impingers)
1	0.8111	0.4471	0.5177	-	1,2582
2	No sample wt	0.6669	0.5965	-	-
3	0.3336	0.4884	0.6661	-	0.8220
4	No sample wt	0.6686	0.3762	-	-
5	0.3108	0.5035	0.4063	-	0.8143
6	0.4412	0.3336	0.5550	-	0.7748

* Impinger catch - composed mainly of sulfur compounds from SO₂ adsorption.

able blank determinations were performed to account for these weights, but because of the relatively lesser weights of particulate matter, the degree of accuracy was extremely limited. As a result, no total particulate loadings were tabulated for these tests. Total weight of material collected in the impingers is reported, although not included in the total sample weight. The significant weight here was contributed by sulfur dioxide adsorption and subsequent formation of sulphurous acid. The reason for the nearly constant values reported is that an equilibrium is formed and the acid formed is very easily swept out of the solution.

The weight determinations for arsenic as performed analytically for the front half wash, glass fibre filter, impinger solution and back half wash are given in Table 7. The total of these weights are used to determine the arsenic emission rates given in Table 4. The ratio, by weight, of impinger contents to total arsenic collected is a measure of the percentage of arsenic which remained in the vapour state at the temperatures under consideration and was subsequently condensed in the impingers. This value remained at or near 1%, except for run no. 4 where a solution of 2% sodium hydroxide was used in the impingers. It was not determined why this value was so low, but it could be assumed that the arsenic was either swept out of the solution during sampling, or lost during analysis.

The percentages of arsenic, iron and antimony in the front half washings for each run are listed in Table 8, those for the filter particulate in Table 9 and for the impinger catch in Table 10. These tables indicate that upwards of 90% of the total arsenic collected was on the glass fibre filter. The values are judged to be very accurate because the arsenic to antimony ratio remained relatively constant in both the front half washings and filter portion, at or near 100:1. Iron, although not a toxic element, was analyzed for as quality control check. If the percentage of arsenic in the total particulate collected were significantly lower than the typical baghouse dust collected, iron should show an upward trend because it is the next most significant element present in that product. The assumption proved valid because the iron values did show an upward trend when comparing the analytical results to a typical baghouse product analysis.

TABLE 7 PARTICULATE ANALYSIS - Arsenic

Run No.	Washings from nozzle, probe & front half of filter holder (g)	Glass fibre filter (g)	Impinger solution (g)	Washings from connectors, impingers & back half of filter holder (g)	Total (g)	Ratio (Impinger) (Total) (%)
1	0.0225	0.1852	0.0025	nil	0.2102	1.19
2	0.0163*	0.2850	0.0033	nil	0.3046	1.08
3	0.0156	0.1752	0.0021	nil	0.1929	1.09
4	0.0178	0.2039	0.0001**	nil	0.2218	0.05
5	0.0238	0.1752	0.0012	nil	0.2002	0.60
6	0.0337	0.1229	0.0015	nil	0.1581	0.95

* Sample spilled in field resulting in lower value being reported.

** 2% NaOH used in impingers.

TABLE 8
PERCENTAGE OF ARSENIC, IRON AND ANTIMONY IN WASHINGS FROM
NOZZLE, PROBE AND FRONT HALF OF FILTER HOLDER

Run No.	Total weight (g)	Arsenic weight (g)	As (%)	Iron weight (g)	Fe (%)	Antimony weight (g)	Sb (%)
1	0.8111	0.0225	2.77	0.0062	0.76	0.0003	0.04
2	No sample wt.	0.0163	---	0.0025	---	0.0002	---
3	0.3336	0.0156	4.68	0.0090	2.70	0.0001	0.03
4	No sample wt.	0.0178	---	0.0080	---	0.0003	---
5	0.3108	0.0238	7.66	0.0130	4.18	0.0004	0.13
6	0.4412	0.0337	7.64	0.0088	1.99	0.0003	0.07
Average			5.69		2.41		0.07

TABLE 9

PERCENTAGE OF ARSENIC, IRON AND ANTIMONY IN FILTER PARTICULATE

Run No.	Filter weight total (g)	Arsenic weight (g)	As (%)	Iron weight (g)	Fe (%)	Antimony weight (g)	Sb (%)
1	0.4471	0.1852	41.42	0.0167	3.74	0.0017	0.38
2	0.6669	0.2850	42.73	0.0196	2.94	0.0031	0.47
3	0.4884	0.1752	35.86	0.0265	5.43	0.0014	0.29
4	0.6686	0.2039	30.50	0.0552	8.26	0.0015	0.22
5	0.5035	0.1752	34.79	0.0240	4.77	0.0023	0.46
6	0.3336	0.1229	36.83	0.0124	3.72	0.0010	0.30
Average			37.02		4.81		0.35

TABLE 10
PERCENTAGE OF ARSENIC, IRON AND ANTIMONY IN IMPINGER CATCH

Run No.	Total weight (g)	Arsenic weight (g)	As (%)	Iron weight (g)	Fe (%)	Antimony weight (g)	Sb (%)
1	0.5177	0.0025	0.48	0.0002	0.04	0.0001	0.02
2	0.5965	0.0033	0.55	0.005	0.08	0.0003	0.05
3	0.6661	0.0021	0.32	<0.0001	<0.02	<0.0001	<0.02
4	0.3762	0.0001	0.03	0.0001	0.02	0.00001	0.03
5	0.4036	0.0012	0.30	<0.0001	0.02	<0.0001	<0.02
6	0.5550	0.0015	0.27	0.0001	<0.02	<0.0001	<0.02
Average			0.33		0.03		0.03

Also, run no. 4, the lowest arsenic percentage observed, gave the highest iron value.

The sulphur dioxide emissions determined during one test conducted concurrently with run no. 6 are summarized in Table 11. Appendix II contains detailed sampling data and emission calculations. The values reported are only significant in terms of providing an overall material balance of the effluent and are not indicative of average day-to-day operation.

TABLE 11
SUMMARY OF SULPHUR DIOXIDE EMISSIONS

Parameter	Run No. Is
Date	19/8/75
Time	9:40 - 10:40
Avg stack temp (^o F)	178
Water concentration (%)	6.04
*Stack gas flow rate (SCFM) (see Run No. 6)	24,000
*SO ₂ concentration	
- %	1.42
- ppm	14,200
SO ₂ mass emission	
- lb/h	3,460
- ton/day	42.5

* volumes and pollutant concentrations are reported as a dry basis at 77°F and 29.92 in. Hg.

10 DISCUSSION

Upon investigating the collection of arsenic in the back half (impingers) of the sampling train, a further examination was performed to investigate the sampling train's ability to capture arsenic on the filter media. The quantities of arsenic collected in the impingers represented only 1.0% of the total collected. It has been reported (5) that pure compounds and mixtures containing significant fractions of the volatile substances relative to possible adsorbing materials (eg. stack emissions of As_2O_3) will exhibit vapor concentrations proportioned to their equilibrium vapor concentrations. A plot of concentrations as a function of temperature using published data is depicted in Figure 7. Using this plot, the experimental data were entered for comparison. The concentration of arsenic in the impingers, expressed as $\mu\text{g}/\text{m}^3$, was plotted versus the average stack temperature during that particular experiment. The data thus confirmed the equilibrium vapor concentrations as expressed by Pupp and Lao. The investigation indicates that the application of these test methods under the conditions sampled is quite suitable for sampling of arsenic emissions.

The major problems encountered during these experiments were the inability to maintain complete isokineticity because of the low stack velocities experienced, and the absence of total particulate loadings because of problems in obtaining exact weights of total particulate collected after washing inner surfaces with two percent sodium hydroxide.

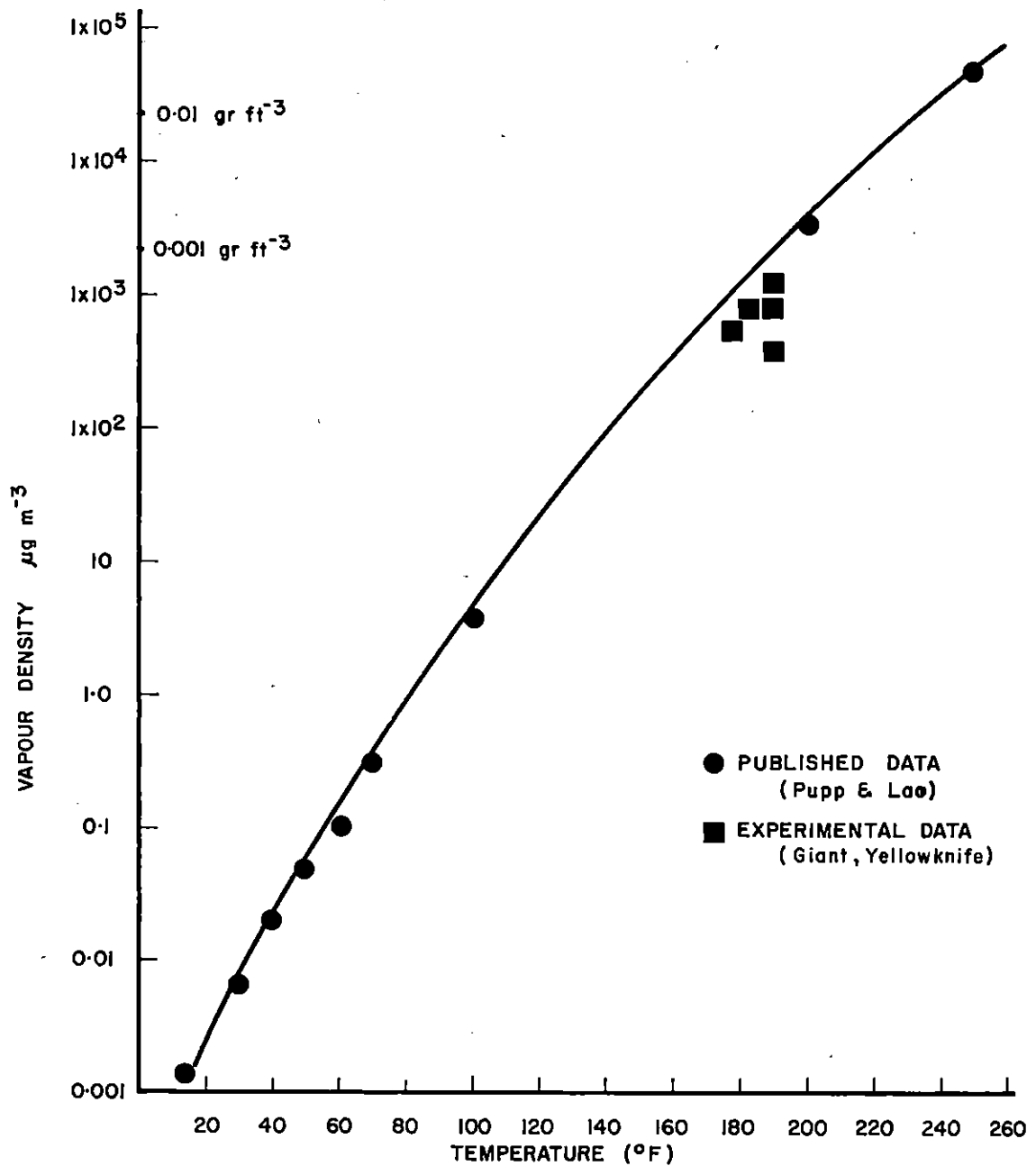


FIGURE 7 - SEMI-LOG PLOT OF THE EQUILIBRIUM VAPOUR CONCENTRATIONS OF ARSENIC AS A FUNCTION OF TEMPERATURE

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APPENDIX I ROASTER STACK SOURCE SAMPLING DATA
GIANT MINES GOLD MINE, YELLOWKNIFE, NWT

APPENDIX I

ROASTER STACK SOURCE SAMPLING DATA

GIANT MINES GOLD MINE, YELLOWKNIFE, NWT

RUN NO. 1, AUGUST 14, 1975. ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
1	5	0.0162	9.47	168.01
2	5	0.0129	9.47	132.02
3	5	0.0130	9.89	127.16
4	5	0.0125	9.47	126.69
5	5	0.0121	9.11	126.44
6	5	0.0121	9.47	123.28
7	5	0.0123	9.89	118.88
8	5	0.0121	9.47	121.35
9	5	0.0127	9.47	127.25
10	5	0.0124	9.47	124.00
11	5	0.0125	9.47	124.34
12	5	0.0123	8.28	141.32
13	5	0.0107	7.36	137.27
14	5	0.0084	5.91	132.80
15	5	0.0076	5.89	120.96
16	5	0.0076	5.89	119.44
17	5	0.0143	11.14	124.42
18	5	0.0141	10.34	130.47
19	5	0.0141	11.14	120.29
20	5	0.0146	9.52	144.99
21	5	0.0131	9.52	129.49
22	5	0.0127	9.52	125.36
23	5	0.0125	9.52	123.68
24	5	0.0125	7.86	149.19
25	5	-	7.86	-
26	5	0.0105	7.86	125.84
27	5	0.0104	7.86	125.05
28	5	0.0104	6.95	140.08
29	5	0.0092	6.95	124.70
30	5	0.0090	5.94	141.40
31	5	0.0077	5.94	121.42
32	5	0.0076	5.94	118.76
AVERAGE			8.50	129.56

As emission rate:

gr/scf - 0.02995
lb/day - 150.31

RUN NO. 1, AUGUST 14, 1975

TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (°F)	Velocity head (in.H ₂ O)	Orifice pressure drop (in.H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (°F)
1	5	183	0.030	2.25	4.86	63
2	5	183	0.030	1.80	3.86	68
3	5	183	0.033	2.00	3.91	72
4	5	183	0.030	1.80	3.76	76
5	5	183	0.028	1.70	3.62	77
6	5	184	0.030	1.80	3.68	80
7	5	185	0.033	1.80	3.70	80
8	5	185	0.030	1.80	3.62	80
9	5	185	0.030	1.80	3.80	81
10	5	185	0.030	1.80	3.71	82
11	5	184	0.030	1.80	3.74	84
12	5	185	0.023	1.50	3.70	82
13	5	182	0.018	1.00	3.21	82
14	5	178	0.010	0.67	2.51	81
15	5	174	0.010	0.64	2.29	81
16	5	166	0.010	0.64	2.29	81
17	5	187	0.040	2.45	4.30	75
18	5	187	0.035	2.10	4.23	80
19	5	187	0.040	2.40	4.22	83
20	5	187	0.030	1.80	4.38	86
21	5	187	0.030	1.80	3.93	88
22	5	187	0.030	1.80	3.80	88
23	5	188	0.030	1.80	3.75	89
24	5	187	0.020	1.80	3.75	91
25	5	188	0.020	1.20	-	90
26	5	188	0.020	1.20	6.32	89
27	5	187	0.020	1.20	3.13	87
28	5	188	0.015	0.92	3.11	89
29	5	186	0.015	0.92	2.77	88
30	5	184	0.010	0.63	2.70	89
31	5	184	0.010	0.63	2.31	88
32	5	183	0.010	0.63	2.27	88
AVERAGE		184		1.535		81

Total gas meter volume - 108.32 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (Hg) 29.24
 Duct area (ft²) 63.62
 Gas flow (acf/min) 32,425.00
 Gas flow (scf/min) 24,390.00
 Stack gas mol. wt. 28.45

Sampling data

Nozzle diameter (in) 0.50
 Moisture content(%) 7.68
 Probe temp(°F) 175.0
 Filter holder temp(°F) 195.0
 Probe length (ft) 10.0

RUN NO. 2, AUGUST 15, 1975. ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
17	5	0.0116	9.40	116.53
18	5	0.0118	9.41	117.41
19	5	0.0117	9.39	116.52
20	5	0.0117	8.60	126.44
21	5	0.0107	9.40	105.57
22	5	0.0115	9.40	113.74
23	5	0.0117	9.42	115.55
24	5	0.0117	8.62	126.27
25	5	0.0108	7.78	128.57
26	5	0.0097	9.40	95.88
27	5	0.0118	7.78	140.46
28	5	0.0098	7.69	118.00
29	5	0.0096	6.85	129.42
30	5	0.0085	6.85	114.61
31	5	0.0084	6.85	112.47
32	5	0.0084	6.85	112.69
1	5	0.0104	8.61	118.44
2	5	0.0110	9.40	113.62
3	5	0.0115	9.40	118.68
4	5	0.0116	9.40	118.60
5	5	0.0116	9.40	118.50
6	5	0.0115	9.39	116.87
7	5	0.0116	9.41	117.31
8	5	0.0116	9.40	116.54
9	5	0.0093	9.40	92.76
10	5	0.0140	8.61	152.94
11	5	0.0108	7.77	129.98
12	5	0.0099	6.85	134.31
13	5	0.0085	5.86	134.52
14	5	0.0071	5.83	112.16
15	5	0.0070	5.85	109.86
16	5	0.0070	5.86	110.11
AVERAGE			8.26	118.92

As emission rate:

gr/scf - 0.04873
lb/day - 238.32

RUN NO. 2, AUGUST 15, 1975 TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (^o F)	Velocity head (in.H ₂ O)	Orifice pressure drop (in.H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (^o F)
17	5	191	0.030	1.58	3.48	88
18	5	192	0.030	1.58	3.53	92
19	5	188	0.030	1.58	3.51	92
20	5	188	0.025	1.31	3.51	94
21	5	191	0.030	1.58	3.20	97
22	5	191	0.030	1.58	3.46	99
23	5	193	0.030	1.58	3.51	99
24	5	191	0.025	1.31	3.51	97
25	5	193	0.020	1.05	3.23	99
26	5	191	0.030	1.58	2.91	98
27	5	193	0.020	1.05	3.54	100
28	5	192	0.020	1.05	2.94	100
29	5	188	0.015	0.78	2.89	99
30	5	188	0.015	0.78	2.56	99
31	5	189	0.015	0.78	2.51	100
32	5	189	0.015	0.78	2.52	100
1	5	191	0.025	1.31	3.11	66
2	5	191	0.030	1.57	3.29	71
3	5	190	0.030	1.57	3.46	75
4	5	190	0.030	1.57	3.49	80
5	5	190	0.030	1.57	3.50	82
6	5	189	0.030	1.57	3.46	83
7	5	191	0.030	1.57	3.48	85
8	5	190	0.030	1.57	3.48	88
9	5	190	0.030	1.57	2.78	90
10	5	190	0.025	1.31	4.21	91
11	5	190	0.020	1.05	3.24	93
12	5	189	0.015	0.78	2.96	93
13	5	186	0.010	0.53	2.55	92
14	5	178	0.010	0.53	2.14	92
15	5	185	0.010	0.53	2.09	94
16	5	186	0.010	0.53	2.09	94
AVERAGE		190		1.22		92

Total gas meter volume - 96.49 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (in Hg) 29.53
 Duct area (ft²) 63.62
 Gas flow (acf/min) 31,510.00
 Gas flow (scf/min) 23,780.00
 Stack gas mol. wt. 28.94

Sampling data

Nozzle diameter (in) 0.50
 Moisture content (%) 7.53
 Probe temp. (^oF) 185.0
 Filter holder temp(^oF) 195.0
 Probe length (ft) 10.0

RUN NO. 3, AUGUST 16, 1975 ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
1	5	0.0114	9.46	118.72
2	5	0.0111	9.07	119.49
3	5	0.0110	9.46	112.46
4	5	0.0112	9.45	113.92
5	5	0.0103	8.66	113.74
6	5	0.0104	8.66	113.86
7	5	0.0104	8.66	113.60
8	5	0.0110	9.46	109.72
9	5	0.0120	9.87	113.63
10	5	0.0116	8.66	124.93
11	5	0.0108	8.66	116.60
12	5	0.0097	7.80	116.03
13	5	0.0074	5.90	116.86
14	5	0.0055	4.11	124.09
15	5	0.0061	4.10	138.55
16	5	0.0040	4.10	90.51
17	5	0.0115	9.46	115.32
18	5	0.0115	9.46	114.78
19	5	0.0107	8.66	116.34
20	5	0.0108	8.66	117.52
21	5	0.0110	9.12	113.16
22	5	0.0115	9.45	113.88
23	5	0.0116	9.46	115.06
24	5	0.0116	9.46	114.64
25	5	0.0097	7.81	116.16
26	5	0.0096	8.14	110.33
27	5	0.0086	6.89	116.43
28	5	0.0084	6.89	113.40
29	5	0.0071	5.89	112.09
30	5	0.0070	5.91	109.79
31	5	0.0070	5.91	110.22
32	5	0.0070	5.91	110.62
AVERAGE			7.91	114.89

Arsenic emission rate:

gr/scf - 0.3318
 lb/day - 155.79

RUN NO. 3, AUGUST 16, 1975

TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (°F)	Velocity head (in.H ₂ O)	Orifice pressure drop (in.H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (°F)
1	5	190	0.030	1.60	3.43	66
2	5	190	0.028	1.45	3.34	71
3	5	190	0.030	1.60	3.30	75
4	5	189	0.030	1.60	3.37	79
5	5	190	0.025	1.30	3.10	82
6	5	190	0.025	1.35	3.12	85
7	5	190	0.025	1.35	3.13	88
8	5	190	0.030	1.60	3.31	90
9	5	190	0.033	1.70	3.59	92
10	5	190	0.025	1.35	3.48	94
11	5	190	0.025	1.10	3.25	94
12	5	188	0.020	1.10	2.92	94
13	5	188	0.010	0.55	2.23	94
14	5	186	0.005	0.30	1.65	93
15	5	185	0.005	0.30	1.84	92
16	5	185	0.005	0.25	1.20	91
17	5	190	0.030	1.58	3.46	87
18	5	190	0.030	1.58	3.45	88
19	5	189	0.025	1.35	3.22	90
20	5	190	0.025	1.35	3.25	90
21	5	189	0.028	1.48	3.31	92
22	5	189	0.030	1.58	3.45	92
23	5	190	0.030	1.58	3.49	93
24	5	190	0.030	1.59	3.49	95
25	5	190	0.020	1.05	2.92	94
26	5	190	0.022	1.11	2.89	94
27	5	190	0.015	0.80	2.58	93
28	5	189	0.015	0.80	2.52	94
29	5	185	0.010	0.54	2.14	93
30	5	189	0.010	0.53	2.09	93
31	5	190	0.010	0.54	2.10	94
32	5	190	0.010	0.54	2.10	92
AVERAGE		189		1.14		89

Total gas meter volume - 89.73 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (Hg) 29.53
 Duct area (ft²) 63.62
 Gas flow (acf/min) 34,600.00
 Gas flow (scf/min) 25,925.00
 Stack gas mol. wt. 28.50

Sampling data

Nozzle diameter (in) 0.50
 Moisture content (%) 7.65
 Probe temp (°F) 165.0
 Filter holder temp (°F) 195.0
 Probe length (ft) 10.0

RUN NO. 4, AUGUST 17, 1975

ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
1	5	0.0116	9.50	119.25
2	5	0.0117	9.50	120.04
3	5	0.0117	9.50	119.15
4	5	0.0117	10.34	108.89
5	5	0.0127	9.49	126.97
6	5	0.0119	8.68	129.16
7	5	0.0109	9.50	108.81
8	5	0.0119	10.34	108.33
9	5	0.0127	9.51	125.15
10	5	0.0119	8.68	127.31
11	5	0.0109	9.49	106.35
12	5	0.0119	9.49	116.50
13	5	0.0120	8.65	127.58
14	5	0.0109	6.89	145.06
15	5	0.0087	6.87	116.41
16	5	0.0086	6.87	115.16
17	5	0.0118	9.53	118.09
18	5	0.0126	10.35	115.07
19	5	0.0128	10.35	116.68
20	5	0.0128	10.35	116.06
21	5	0.0126	10.35	113.74
22	5	0.0134	11.14	113.08
23	5	0.0124	10.35	111.72
24	5	0.0124	10.35	112.02
25	5	0.0120	9.52	117.66
26	5	0.0119	9.51	116.79
27	5	0.0111	8.69	119.64
28	5	0.0120	8.69	117.97
29	5	0.0100	7.86	118.47
30	5	0.0095	7.84	113.14
31	5	0.0075	5.93	117.02
32	5	0.0072	5.94	113.30
AVERAGE			9.06	117.83

Arsenic emission rate:

gr/scf - 0.032
lb/day - 175.14

RUN NO. 4, AUGUST 17, 1975

TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (°F)	Velocity head (in.H ₂ O)	Orifice pressure drop (in.H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (°F)
1	5	192	0.030	1.65	3.47	71
2	5	192	0.030	1.65	3.52	75
3	5	192	0.030	1.65	3.52	79
4	5	192	0.035	1.90	3.53	83
5	5	191	0.030	1.65	3.81	87
6	5	192	0.025	1.37	3.56	90
7	5	192	0.030	1.65	3.28	90
8	5	192	0.035	1.90	3.57	92
9	5	193	0.030	1.65	3.81	95
10	5	192	0.025	1.37	3.56	98
11	5	191	0.030	1.65	3.26	99
12	5	190	0.030	1.65	3.57	98
13	5	188	0.025	1.37	3.59	100
14	5	184	0.015	0.83	3.27	99
15	5	182	0.015	0.83	2.62	98
16	5	182	0.015	0.83	2.59	98
17	5	195	0.030	1.65	3.54	88
18	5	194	0.035	1.90	3.78	92
19	5	194	0.035	1.90	3.84	93
20	5	193	0.035	1.90	3.83	94
21	5	194	0.035	1.90	3.77	97
22	5	193	0.040	2.20	4.03	96
23	5	193	0.035	1.90	3.72	99
24	5	193	0.035	1.90	3.73	99
25	5	194	0.030	1.65	3.60	99
26	5	193	0.030	1.65	3.57	98
27	5	194	0.025	1.37	3.34	98
28	5	193	0.025	1.37	3.29	97
29	5	193	0.020	1.10	2.99	97
30	5	191	0.020	1.10	2.85	95
31	5	188	0.010	0.55	2.24	95
32	5	191	0.010	0.55	2.16	94
AVERAGE		191		1.51		93

Total gas meter volume - 104.28 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (Hg) 29.43
 Duct area (ft²) 63.62
 Gas flow (acf/min) 34,600.00
 Gas flow (scf/min) 25,925.00
 Stack gas mol. st. 28.50

Sampling data

Nozzle diameter(in) 0.50
 Moisture content (%) 7.65
 Probe temp (°F) 165.0
 Filter holder temp(°F) 195.0
 Probe length (ft) 10.0

RUN NO. 5, AUGUST 18, 1975 ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
1	5	0.0117	9.92	114.03
2	5	0.0125	10.33	116.43
3	5	0.0125	10.33	114.99
4	5	0.0127	9.49	125.58
5	5	0.0118	9.49	116.32
6	5	0.0118	9.49	116.22
7	5	0.0119	9.49	116.25
8	5	0.0119	10.33	106.78
9	5	0.0127	10.33	113.15
10	5	0.0128	9.49	123.12
11	5	0.0120	8.66	127.21
12	5	0.0109	7.84	127.81
13	5	0.0100	6.90	132.27
14	5	0.0087	6.90	114.73
15	5	0.0087	5.91	133.54
16	5	0.0071	5.91	110.34
17	5	0.0125	9.96	118.04
18	5	0.0119	9.49	117.10
19	5	0.0127	9.95	119.33
20	5	0.0127	9.94	119.40
21	5	0.0119	9.50	116.32
22	5	0.0127	9.96	119.11
23	5	0.0128	9.96	119.74
24	5	0.0128	9.96	119.43
25	5	0.0120	9.50	117.34
26	5	0.0109	8.68	117.26
27	5	0.0115	8.67	122.87
28	5	0.0111	9.49	108.74
29	5	0.0099	7.85	116.65
30	5	0.0086	6.92	115.35
31	5	0.0072	5.93	111.81
32	5	0.0073	5.93	113.31
AVERAGE			8.83	118.15

Arsenic emission rate:

gr/scf - 0.03009
lb/day - 157.26

RUN NO. 5, AUGUST 18, 1975

TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (^o F)	Velocity head (in H ₂ O)	Orifice pressure drop (in H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (^o F)
1	5	192	0.033	1.78	3.50	73
2	5	191	0.035	1.90	3.76	78
3	5	190	0.035	1.90	3.76	84
4	5	190	0.030	1.65	3.80	88
5	5	191	0.030	1.65	3.53	90
6	5	191	0.030	1.65	3.54	92
7	5	191	0.030	1.65	3.56	95
8	5	191	0.035	1.90	3.57	97
9	5	191	0.035	1.90	3.80	100
10	5	190	0.030	1.65	3.83	103
11	5	189	0.025	1.35	3.60	100
12	5	189	0.020	1.10	3.28	100
13	5	186	0.015	0.82	3.00	99
14	5	185	0.015	0.82	2.60	99
15	5	185	0.010	0.55	2.59	98
16	5	185	0.010	0.55	2.14	98
17	5	193	0.035	1.90	3.75	93
18	5	191	0.030	1.65	3.57	91
19	5	191	0.035	1.90	3.82	91
20	5	190	0.035	1.90	3.83	90
21	5	192	0.030	1.65	3.56	92
22	5	193	0.035	1.90	3.82	93
23	5	193	0.035	1.90	3.84	93
24	5	193	0.035	1.90	3.83	93
25	5	192	0.030	1.65	3.59	93
26	5	192	0.025	1.35	3.28	92
27	5	191	0.025	1.35	3.44	91
28	5	191	0.030	1.65	3.35	91
29	5	192	0.020	1.10	2.96	92
30	5	190	0.015	0.82	2.59	90
31	5	188	0.010	0.55	2.15	88
32	5	188	0.010	0.55	2.18	88
AVERAGE		190		1.45		94

Total gas meter volume - 102.66 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (Hg) 29.39
 Duct area (ft²) 63.62
 Gas flow (acf/min) 33,700.00
 Gas flow (scf/min) 25,400.00
 Stack gas mol. wt. 28.51

Sampling data

Nozzle diameter(in) 0.50
 Moisture content(%) 7.09
 Probe temp (^oF) 165.0
 Filter holder temp(^oF) 195.0
 Probe length (ft) 10.0

RUN NO. 6, AUGUST 19, 1975

ANALYSIS OF ISOKINETICITY

Traverse point	Sampling time (min)	Actual sampling rate (ft ³ /s)	Stack gas velocity (ft/s)	Percent Isokineticity achieved
1	5	0.0118	9.43	120.60
2	5	0.0125	10.26	117.43
3	5	0.0125	10.26	116.07
4	5	0.0118	9.43	117.77
5	5	0.0119	9.43	118.68
6	5	0.0116	9.43	114.84
7	5	0.0118	9.43	116.12
8	5	0.0118	9.43	115.76
9	5	0.0107	8.62	114.81
10	5	0.0099	7.80	117.22
11	5	0.0108	8.62	114.93
12	5	0.0108	8.62	115.52
13	5	0.0087	6.89	115.87
14	5	0.0072	5.90	111.37
15	5	0.0071	5.90	110.49
16	5	0.0071	5.90	110.43
17	5	0.0097	7.82	116.27
18	5	0.0101	7.80	120.86
19	5	0.0096	7.81	114.57
20	5	0.0099	7.81	116.83
21	5	0.0106	8.63	113.31
22	5	0.0109	8.63	116.20
23	5	0.0098	7.82	115.56
24	5	0.0117	9.46	113.59
25	5	0.0118	9.46	114.53
26	5	0.0119	9.47	114.75
27	5	0.0108	8.64	114.11
28	5	0.0108	8.64	114.25
29	5	0.0099	7.81	115.05
30	5	0.0087	6.89	114.77
31	5	0.0072	5.91	111.34
32	5	0.0072	5.90	111.04
AVERAGE			828	115.15

Arsenic emission rate:

gr/scf - 0.02585
lb/day - 127.64

RUN NO. 6, AUGUST 19, 1975

TRAVERSE DATA

Traverse point	Sample time (min)	Stack gas temp (°F)	Velocity head (in H ₂ O)	Orifice pressure drop (in H ₂ O)	Gas meter vol (ft ³)	Gas meter temp (°F)
1	5	177	0.030	1.65	3.53	67
2	5	177	0.035	1.90	3.76	70
3	5	177	0.035	1.90	3.75	76
4	5	177	0.030	1.65	3.52	79
5	5	177	0.030	1.65	3.57	83
6	5	177	0.030	1.65	3.48	87
7	5	177	0.030	1.65	3.54	89
8	5	178	0.030	1.65	3.53	90
9	5	178	0.025	1.35	3.21	92
10	5	179	0.020	1.10	2.97	93
11	5	179	0.025	1.35	3.23	95
12	5	180	0.025	1.35	2.45	96
13	5	179	0.015	0.83	2.61	96
14	5	177	0.010	0.55	2.15	94
15	5	177	0.010	0.55	2.13	94
16	5	178	0.010	0.55	2.13	94
17	5	181	0.020	1.10	2.92	88
18	5	179	0.020	1.10	3.04	89
19	5	180	0.020	1.10	2.89	91
20	5	179	0.020	1.10	2.96	93
21	5	180	0.025	1.35	3.18	95
22	5	181	0.025	1.35	3.27	97
23	5	181	0.020	1.10	2.95	98
24	5	181	0.030	1.65	3.51	99
25	5	182	0.030	1.65	3.54	100
26	5	183	0.030	1.65	3.56	102
27	5	181	0.025	1.35	3.24	102
28	5	181	0.025	1.35	3.25	102
29	5	180	0.020	1.10	2.96	102
30	5	179	0.015	0.83	2.61	102
31	5	179	0.010	0.55	2.17	101
32	5	177	0.010	0.55	2.17	99
AVERAGE		178		1.26		92

Total gas meter volume - 94.365 scf

Total sample time - 160 min

Stack conditions during test

Abs. stack pressure (Hg)	29.37
Duct area (ft ²)	63.62
Gas flow (acf/min)	32,600.00
Gas flow (scf/min)	24,000.00
Stack gas mol. wt.	28.33

Sampling data

Nozzle diameter(in)	0.50
Moisture content(%)	8.02
Probe temp (°F)	150.0
Filter holder temp(°F)	195.0
Probe length (ft)	10.0

APPENDIX II

GASEOUS SO₂ SAMPLING DATA

TRAVERSE DATA

Traverse Point	Sample time (min)	Stack gas temp (°F)	Gas meter vol (ft ³)	Gas meter rate (ft ³ /min)	Gas meter temp (°F)	Gas meter vac. (in Hg)
1	0	177	0.00		65	8.0
	5	177			66	10.3
	10	177	4.82	0.482	66	10.2
	15	177			66	10.2
	20	177	9.93	0.511	67	10.1
	25	179			68	10.2
	30	179			68	10.2
	35	178	17.50	0.505	68	10.2
	40	179			68	10.1
	45	179	23.05	0.555	68	10.1
	50	180			69	10.4
	55	179			69	10.4
	60	179	29.75	0.447	69	10.5
AVERAGE		178		0.496	68	10.1

Total sample time - 60 min

Meter calibration factor - 0.967

Water collected in impingers - 25.7 mls

Corrected meter volume - 28.77 cf

Flow conditions during test:

Abs. stack pressure (Hg) - 29.37

Percent moisture - 6.04

SO₂ EMISSION CALCULATIONS

Test	Date	Sample Vol (Vm) ml	Absorption Solution Vol (V Soln) ml	Volume of aliquot (Va) ml	Volume of titrant (vt) ml
1S	19/8/75	28.77	a) 1000 b) 100	a) 40 b) 20	26.25

$$(1) V_{SO_2} = \frac{V_t \times 125 \times N \times T_m \times 2.4 \times 10^{-5}}{P_b - P_m}$$

Where:

V_{SO_2} = volume of SO₂ sampled (at meter conditions) ft³
 N = normality of titrant = 0.204
 T_m = average meter temperature (°R)
 P_b = barometric pressure (in Hg)
 P_m = average meter vacuum (in Hg)

$$V_{SO_2} = 0.44 \text{ ft}^3$$

$$(2) V_{H_2O} = \frac{0.00267 \times V_w \times T_m}{P_b - P_m}$$

Where:

V_{H_2O} = total volume of water vapor in the sample (ft³)
 V_w = water collected in impingers
 $V_{H_2O} = 1.88 \text{ ft}^3$

$$(3) V_{total} = V_m + V_{H_2O} + V_{SO_2}$$

Where:

V_{total} = volume of stack gases sampled at meter conditions (Tm & Pm)

$$V_{total} = 31.09 \text{ ft}^3$$

$$(4) \quad \% \text{SO}_2 = \frac{\text{VSO}_2 \times 100}{\text{V}_{\text{total}}}$$

$$\% \text{SO}_2 = 1.42$$

(5) SO_2 mass emission (tons/day)

$$\text{SO}_{2\text{ER}} = \frac{Q \times \% \text{SO}_2 \times 86400 \times 3.7728 \times 10^{-5} \times 2.24}{100}$$

Where:

$\text{SO}_{2\text{ER}}$ = weight of sulphur dioxide emitted to the atmosphere (tons/day)

Q = volume rate of flow of flue gas at 70°F and 29.92 in Hg (cfs) (see Run No.6 - particulates)

$$\text{SO}_{2\text{ER}} = 41.5 \text{ tons/day}$$

APPENDIX III PROCESS DESCRIPTION

APPENDIX III PROCESS DESCRIPTION

The gold mining operation involves five major steps:

- a) crushing, grinding and classification,
- b) flotation,
- c) roasting,
- d) calcine wash, and
- e) calcine extraction.

Crushing, Grinding and Classification

Most ore passes through a 36 in. x 48 in. primary jaw crusher located underground. Ore that is not crushed is passed through 18 in. x 30 in. grizzlies before hoisting. Both crushed and uncrushed muck is skipped to a 500 ton course bin on the surface.

The surface crushing plant has a capacity of 150 tons per hour when crushing to 3/8 in. Ore from the course bin is conveyed to a 30 in. x 42 in. jaw set at 4 in. The crushed material is conveyed to a vibrating rubber scalping screen with 2 in. square openings. Oversize enters a 4 1/4 ft. standard cone crusher. The product joins undersize from the scalping screen for conveying to a pair of 5 ft. x 10 ft. double-deck vibrating screens operating in parallel. The oversize is conveyed to a surge bin which feeds two 4 ft. short-head crushers operating in parallel. The minus product is elevated to the top of four 500-ton, flat-bottomed silos.

Primary grinding is divided into two stages, each consisting of an 8 ft. x 10 ft. scoop-fed ball mill and a 72 in. high wire spiral classifier in closed circuit. The gathering belt feeding each mill is equipped with a belt scale. Nickel-hard single-wave, continuous liners are used in the primary mills. The grinding media is 3 in. forged steel balls.

Pulp from the mills is heated by the addition of warm water to the grinding circuit. The classifier overflow, at 44% minus 200 mesh, proceeds to a vibrating screen for removal of wood chips.

Flotation

Entering the flotation circuit at 40% solids, the overflow is split and fed to two, 12-cell parallel banks of #24 DR cells. Tails are then fed to a 6 ft. x 12 ft. mill for regrinding. This unit is in closed circuit with a pair of 10 in. cyclones. Overflow is pumped and split fed

to two, 10-cell parallel banks of #24 DR cells. The final flotation tailings report to the backfill plant. All concentrate is united to form the roaster feed.

Roasting

Bulk flotation not only concentrates gold, but must, because of the type of ore, concentrate the arsenic and antimony content. To overcome this objectionable association in the concentrate and to free gold for cyanidation, physical and chemical breakdown is necessary prior to leaching. This is accomplished in a two-stage Fluo Solids roaster. The purpose of roasting is to produce porous particles by volatilization of arsenic, antimony, and sulphur, thereby exposing gold. By eliminating a high percentage of arsenic and by controlling conditions of the roast to preclude formation of arsenates and magnetite, calcine is made amenable to cyanidation.

Flotation concentrate is pumped to a 6 in. cyclone. Underflow product reports to a 10 ft. x 10 ft. surge agitator while the fines go to a double-compartment 40 ft. x 12 ft. thickener. The thickened product together with surge agitator material is pumped to a 24 ft. x 18 ft. blending and storage agitator. The aim here is to achieve a consistent assay grade in the roaster feed. Concentrate is then pumped, via a three way splitter box, to a 6 ft. diameter, three disc filter located directly over a slurry agitator. The cake falls into a 6 ft. x 6 ft. agitator and is repulped to a density of 78%. The purpose of the filter, splitter box and slurry agitator arrangement is to maintain a constant feed density.

A 2D10 Moyno pump with vari-speed drive meters feed from the slurry agitator to a 3 ft. x 3 ft. SRL-C pump for delivery to the feed gun on the first stage reactor. A densi-dyne instrument, using pneumatic forced balance as the Moyno discharge travels through a U-tube, regulates a water valve to adjust density in the slurry agitator.

The roaster feed gun operates with 18 cfm air at 100 psi. The gun introduces feed through the top of the first stage vessel at an angle of 85° to the vessel top. A low-pressure, 5000 cfm turbo blower supplies air to the first stage for fluidization and to support autogenous roasting. The vessel has a working diameter of 13 feet. Air enters the windbox at 64 oz. pressure through 193 tuyeres. Specified conditions ensure a reducing atmosphere for elimination of arsenic. Calcine leaves this stage

and enters the second stage through a fluoseal and air lift arrangement. Gases pass from the freeboard zone of the reducing reactor through a cyclone to the freeboard of the second stage.

The second stage vessel has a 14 ft. working diameter. Air is supplied at 64 oz. pressure from a 2100 cfm turbo blower through 216 tuyeres. An oxidizing atmosphere is provided in this stage to facilitate formation of volatile arsenious oxide and to convert magnetite to hematite. Dust-laden roaster gases are directed to two cyclones in tandem. Underflow from the cyclones are water-quenched and join the quenched bed calcine prior to pumping to a calcine wash circuit. Gas, along with the remaining dust load, proceeds to a Cottrell plant.

Feed rate is in the area of seven tons of solid per hour in a slurry of 78% solids. Consequently, the roaster treats 170 tons per day, of which about 130 tons is recovered in calcine; the remainder being lost with the gases in the form of arsenic trioxide (As_2O_3), antimony trioxide (Sb_2O_3), sulphur dioxide (SO_2), and fine dust particles.

Tables 1 and 2 give typical product assays and roaster operating conditions respectively.

Calcine Wash

Quenched calcine is pumped to a 10 in. cyclone where fine material is removed and enters a 30 ft. x 10 ft. decanting thickener. The cyclone underflow reports to a 5 ft. x 8 ft. ball mill via a pair of 6 in. cyclones, in closed circuit with the mill, where a fresh water grind is applied. Overflow from the 5 in. cyclones combines with decant thickener underflow for pumping to a 40 ft. x 12 ft. calcine wash thickener. Underflow is filtered by one of two 11 1/2 ft. x 16 ft. drum filters. Cake is repulped in fresh water while filtrate is returned to the wash thickener.

Calcine Extraction Circuit

Repulped filter cake is pumped to a 5 ft. x 8 ft. ball mill in closed circuit with a 10 in. cyclone where cyanide and lime are added. Overflow at 75% minus 325 mesh enters the first stage cyanide circuit for agitation, thickening and filtering. Repulping in barren solution, the filter cake enters a similar second stage cyanide circuit before discharge of the calcine residue. Filtrates, together with thickener overflows, enter pregnant solution tanks

prior to withdrawal for the precipitation circuits.

The precipitation circuit consists of two standard Merrill-Crowe units operating in parallel. Each unit has a leaf clarifier, a deaerating tower, a zinc dust feeding system and two 36 in. square presses.