

## VIII. APPENDIX

### SAMPLING AND ANALYSIS

The sampling and analytical procedures are based on Method No. P&CAM 173 of the NIOSH Manual of Analytical Methods [268], the NIOSH Manual of Sampling Data Sheets [269], the Complete Testing of NIOSH Method for the Determination of Trace Metals by Atomic Absorption Spectrophotometry [266], and updates by NIOSH, Inorganic Methods Development Section.

Sample analysis by atomic absorption spectrophotometry (AAS) is probably the most economical method for the measurement of cobalt. NIOSH recommends this method for determining compliance with the Federal standard for cobalt.

#### General Sampling Requirements

Collect personal samples in the breathing zone of individual workers without interfering with the workers' freedom of movement. Enough samples should be obtained to permit calculation of a TWA concentration and to evaluate the exposure of each worker at every operation or location in which there is workplace exposure to cobalt. Record the sampling locations and conditions, including ambient temperature and pressure as needed, equipment used, time and rate of sampling, and any other pertinent information.

#### Equipment for Air Sampling

(a) Filter: 37-mm cellulose ester membrane filter with a pore size of 0.8  $\mu\text{m}$  should be mounted with backup pad in a two- or three-piece closed-face cassette.

(b) Battery-operated personal sampling pump: The pump should have a device, such as a clip, for attachment to the worker's clothing. All pumps and flowmeters must be calibrated using a calibrated test meter or other reference, as described in Calibration of Equipment. Battery-operated pumps should be capable of operating at flowrates of 1-2 liters/min to maintain a face velocity of 2.6 cm/s and must be capable of up to 8 hours of continuous operation without recharging.

(c) Thermometer.

(d) Manometer.

(e) Stopwatch.

(f) Various clips, tubing, spring connectors, or belt sufficient to connect sampling apparatus to worker being sampled.

## Calibration of Equipment

Since the accuracy of an analysis can be no greater than the accuracy with which the volume of air is measured, accurate calibration of the sampling pump is essential. The frequency of calibration required depends on the use, care, and handling that the pump receives. Pumps should be recalibrated if they have been abused or if they have just been repaired or received from the manufacturer. Maintenance and calibration should be performed on a routine schedule, and records of these should be maintained.

Ordinarily, to collect a large number of field samples, pumps should be calibrated in the laboratory both before and after they have been used. If extensive field sampling is performed, the pumps should be calibrated periodically during sampling to ensure continuous satisfactory operation of the pump and sampler. The accuracy of calibration depends on the type of instrument used as a reference. The choice of calibration instrument will depend largely on where the calibration is to be performed. For laboratory testing, a spirometer or soapbubble meter is recommended, although other calibration instruments such as a wet-test meter, dry gas meter, or calibrated rotameter can be used. The calibration instrument should be calibrated to +5%. The actual setups will be similar for all instruments.

The calibration setup for a personal sampling pump with a membrane filter is shown in Figure X-5. Since the flowrate given by a pump depends on the pressure drop across the sampling device, the pump must be calibrated while operating with a representative filter in line. Instructions for calibration with the soapbubble meter follow. If another calibration device is selected, equivalent procedures should be used.

- (a) Check the voltage of the pump battery with a voltmeter to ensure adequate voltage for calibration. Charge the battery if necessary.
- (b) Place a membrane filter in the holder.
- (c) Assemble the sampling train.
- (d) Turn on the pump and moisten the inside of the soapbubble meter by immersing the buret in the soap solution and drawing bubbles up the inside until they are able to travel the entire length of the buret without bursting.
- (e) Adjust the pump flow controller to provide the desired flowrate.
- (f) Check the water manometer to ensure that the pressure drop across the sampling train does not exceed 33 cm of water (approximately 2.54 cm of mercury).
- (g) Start a soapbubble up the buret and measure with a stopwatch the time the bubble takes to move from one calibration mark to another.
- (h) Repeat the procedure in (g) at least three times, average the results, and calculate the flowrate by dividing the volume between the

preselected marks by the time required for the soapbubble to traverse the distance.

(i) Record the data for the calibration including volume measured, elapsed time, pressure drop, air temperature, atmospheric pressure, serial number of the pump, data, and the name of the person performing the calibration.

### Collection Samples

(a) Assemble a sampling train consisting of the recommended size cellulose ester membrane filter with a portable, battery-operated personal sampling pump.

(b) Establish the calibrated flowrate as accurately as possible, using the manufacturer's directions. The recommended sampling flowrate is 1.5 liter/min, corresponding to a sampling volume of 0.72 cu m for an 8-hour sample or about 0.02 cu m for a 15-minute sample.

(c) Measure and record the temperature and pressure of the atmosphere being sampled, as needed.

(d) Record the elapsed time. The sample volume is obtained by multiplying the flowrate by the elapsed time.

(e) Immediately after sampling, replace the plugs in the cassette.

(f) Treat at least one filter in the same manner as the sample (open and reclose cassette, seal, and ship), but do not draw air through it. This filter will serve as a blank.

### Principle of the Analytical Method

The sample, collected on a cellulose membrane filter, is ashed using a mixture of nitric acid and perchloric acid [266] to destroy the organic matter and to bring cobalt into solution. Samples, blanks, and standards are aspirated into the air-acetylene flame of the AAS. A hollow cathode lamp for cobalt provides a characteristic line at 240.7 nm [268]. The absorption of this line by the ground-state atoms in the flame is proportional to the cobalt concentration in the aspirated sample.

### Range and Sensitivity

For cobalt, the absolute detection limit is approximately 0.01  $\mu\text{g}$  cobalt/ml, but the lower limit for quantitative determination is 0.2  $\mu\text{g}$  cobalt/ml. The upper limit for quantitative determination is 5.0  $\mu\text{g}$  cobalt/ml, but the method can be extended to a higher concentration by dilution of the sample. For a 10-ml solution and 0.72 cu m of sampled air,

this corresponds to a range of 2.8-70  $\mu\text{g}/\text{cu m}$ . For a 0.02-cu m sample, the lower limit corresponds to 100  $\mu\text{g}/\text{cu m}$ .

### Interferences

Physical interferences may result if the physical properties of the samples vary significantly. Changes in viscosity and surface tension can affect the sample aspiration rate and thus cause erroneous results. Sample dilution or the method of standard additions are used to correct such interferences. High concentrations of silicates in the sample can cause an interference and may cause aspiration problems. If large amounts of silicates are extracted from the samples, the samples should be allowed to stand for several hours and be centrifuged or filtered to remove the silicates.

Background or nonspecific absorption can occur from particles produced in the flame, which can scatter the incident radiation, causing an apparent absorption signal. Light-scattering problems may be encountered when solutions of high salt content are being analyzed. Light-scattering problems are most severe when measurements are made at the lower wavelengths, ie, below about 250 nm. Background absorption may also occur as the result of the formation of various molecular species that can absorb light. The background absorption should be accounted for by the use of background correction techniques, preferably by the use of a nonabsorbing wavelength, and, if necessary, by the use of D2 or H2 continuum.

### Precision and Accuracy

For analysis only, the relative standard deviation (RSD) is 54% at 0.05  $\mu\text{g}$  cobalt/ml, compared with a RSD of 9% at 0.2  $\mu\text{g}$  cobalt/ml. From 0.5 to 5  $\mu\text{g}$  cobalt/ml, the RSD of the analytical measurement is approximately 3% [268].

### Advantages and Disadvantages

The method is rapid because there is little sample preparation involved. It can be performed with generally available laboratory equipment and by general laboratory personnel, and it is sufficiently sensitive. However, the method measures total cobalt and is not capable of distinguishing individual cobalt compounds.

### Apparatus and Equipment

- (a) Hollow cathode lamp for cobalt.
- (b) Atomic absorption spectrophotometer equipped with a burner head for air-acetylene flame.

(c) Oxidant: Air supply, with a minimum pressure of 40 pounds per square inch, filtered to remove oil and water.

(d) Fuel: Acetylene, commercially available for atomic absorption use.

(e) Pressure-reducing valves: A two-gauge, two-stage pressure-reducing valve and appropriate hose connections for each compressed gas tank used.

(f) Glassware, borosilicate:

(1) 125-ml Phillips or Griffin beakers with watchglass covers.

(2) 15-ml graduated centrifuge tubes.

(3) 10-ml volumetric flasks.

(4) 100-ml volumetric flasks.

(5) 1-liter volumetric flasks.

(6) 125-ml polyethylene bottles.

Additional auxiliary glassware such as pipets and different size volumetric glassware will be required depending on the elements being determined and the dilutions required to have sample concentrations above the detection limit and in the linear response range. All pipets and volumetric flasks required in this procedure should be calibrated class A volumetric glassware.

(g) Hotplate (suitable for operation at 140°C).

### Reagents

(a) Purity: ACS analytical reagent grade chemicals or equivalent should be used in all tests. References to water shall be understood to mean double distilled water or equivalent. Care in selection of reagents and in following the listed precautions is essential if low blank values are to be obtained.

(b) Concentrated nitric acid (68-71%), redistilled, specific gravity 1.42.

(c) Standard stock solutions (1,000  $\mu\text{g}/\text{ml}$  for cobalt), commercially prepared or prepared per instrument manufacturer's recommendations.

(d) Perchloric acid, reagent grade.

## Procedure

### (a) Cleaning of Equipment

Before initial use, clean glassware with saturated solution of sodium dichromate in concentrated sulfuric acid and then rinse thoroughly with warm tapwater, concentrated nitric acid, tapwater, and deionized water, in that order, and then dry. Soak all glassware in a mild detergent solution immediately after use to remove any residual grease or chemicals. For glassware that has previously been subjected to the entire cleaning procedure, it is not necessary to use the chromic acid cleaning solution. This glassware should be cleaned in 1:1 diluted nitric acid and rinsed several times with distilled water.

### (b) Preparation of Samples

Transfer samples and blanks (a minimum of 1 filter blank for every 10 filter samples) to clean 125-ml beakers, and add 1 ml of concentrated HClO<sub>4</sub> and 6 ml of concentrated HNO<sub>3</sub> to each. Cover each beaker with a watchglass, and heat on a hot plate (140°C) in a fume hood. Completion of digestion is indicated by a colorless solution or a white residue in the beaker. Once the ashing is complete, remove the watchglass, and allow the sample to evaporate to near dryness (approximately 0.5 ml). If charring occurs, add HNO<sub>3</sub> (1 ml) and evaporate to near dryness (0.5 ml) again. Repeat, if necessary.

Remove the beaker from the hotplate, cool, and add 1 ml HNO<sub>3</sub> and 2-3 ml of distilled water. Transfer the solution quantitatively with distilled water to a 10-ml volumetric flask, and then dilute the samples to volume (10 ml) with water.

The 10-ml solution may be analyzed directly for any element of very low concentration in the sample that was dissolved by this ashing procedure. Aliquots of this solution may then be diluted to an appropriate volume for cobalt present at higher concentrations.

### (c) Analysis of Samples

Set the instrument operating conditions as recommended by the manufacturer. The instrument should be set at 240.7 nm for cobalt.

Match standard solutions with the sample matrix as closely as possible, and run in duplicate. Aspirate working standard solutions, freshly prepared each day, into the flame, and record the absorbance. Prepare a calibration graph as described in a later section. (Note: All combustion products from the atomic absorption flame must be removed by direct exhaustion through the use of a good separate flame ventilation system.) Blank filters must be carried through the entire procedure each time samples are analyzed.

Aspirate the appropriately diluted samples directly into the instrument, and record the absorbance for comparison with standards. Should the absorbance be above the calibration range, dilute an appropriate aliquot to 10

ml. Aspirate water after each sample. As a minimum, a midrange standard must be aspirated with sufficient frequency, ie, once every five samples, to ensure the accuracy of the sample determinations. It is best to run a standard with a concentration close to that of a sample after each sample is run. To the extent possible, base all determinations on replicate analyses.

### Calibration and Standards

(a) Dilute standards (100  $\mu\text{g}$  metal/ml). Pipet 10 ml of the stock (1,000  $\mu\text{g}$  cobalt/ml) into a 100-ml volumetric flask, add 10 ml  $\text{HNO}_3$ , and dilute to volume with distilled water. Prepare fresh standards at least weekly, preferably with each use, and store in polyethylene bottles. Polyethylene containers are suitable for storage because of their low metallic content and nonpolar surfaces.

(b) Working standards. Prepare working standards by dilution of the dilute standards or the stock standards so that the final acid concentration is the same for the samples and standards, ie, 10% V/V  $\text{HNO}_3$ , 5% V/V  $\text{HClO}_4$ . Concentrations of the working standards should cover the range 0.5-5.0  $\mu\text{g}/\text{ml}$ . Prepare fresh solutions daily.

(c) Standard solutions. Aspirate standard solutions into the flame, and record the absorbance (or concentration). If the instrument used displays transmittance, convert these values to absorbance. Prepare a calibration curve by plotting absorbance (units) vs metal concentration. The best fit curve (calculated by linear least square regression analysis) is fitted to the data points. This line, or the equation describing the line, is used to obtain the cobalt concentration in the samples being analyzed.

(d) Preparation procedure. To ensure that the preparation procedure is being properly followed, spike clean membrane filters with known amounts of cobalt by adding appropriate amounts of the previously described standards, and carry them through the entire procedure. Determine the amount of cobalt, and calculate the percent recovery. These tests will provide recovery and precision data for the procedure as it is carried out in the laboratory for the soluble cobalt compounds being determined.

(e) Analysis by the method of standard additions. In order to check for interferences, analyze samples initially and periodically by the method of standard additions, and compare the results with those obtained by the conventional analytical determination. For this method, divide the sample into three 2-ml aliquots. To one of the aliquots, add an amount of cobalt approximately equal to that in the sample. To another aliquot add twice this amount. (Note: Additions should be made by micropipetting techniques so that the volume does not exceed 1% of the original aliquot volume, ie, 10- $\mu\text{l}$  and 20- $\mu\text{l}$  additions to a 2-ml aliquot. This method should be applied only if the concentration of cobalt in the solutions is sufficiently low that absorbance is linearly related to concentration.) Then analyze the solutions, and plot the absorbance readings against metal added to the original sample. The line obtained from such a plot is extrapolated to zero absorbance, and the

intercept on the concentration axis is taken as the amount of metal in the original sample. If the result of this determination does not agree to within 10% of the values obtained with the procedure described in (c), an interference is indicated and standard addition techniques should be utilized for sample analysis.

### Calculations

(a) The estimated air volume may need to be corrected for elevation and temperature. For personal sampling pumps with rotameters only, the following correction for air volume should be made:

$$V = \frac{f \times t}{1,000} \left( \sqrt{\frac{P_1 \times T_2}{P_2 \times T_1}} \right)$$

where:

- V = sample volume (cu m)
- f = sample flowrate (liters/min)
- t = sampling time (minutes)
- P1 = pressure during calibration of sampling pump (in mmHg)
- P2 = pressure air samples (in mmHg)
- T1 = temperature during calibration of sampling pump (K)
- T2 = temperature of air sampled (K)

(b) The uncorrected volume collected by the filter is calculated by averaging the beginning and ending sample flowrates, converting to cubic meters, and multiplying by the sample collection time. The formula for this calculation is:

$$V = \frac{(f_b + f_e)t}{2,000}$$

where:

- V = sample volume (cu m)
- f<sub>b</sub> = sample flowrate at beginning of sample collection (liter/min)
- f<sub>e</sub> = sample flowrate at end of sample collection (liter/min)
- t = sample collection time (minutes)

(c) Cobalt concentrations are calculated by multiplying the micrograms of cobalt/ml in the sample aliquot by the aliquot volume and dividing by the volume of air sampled by the filter:

$$\mu\text{g cobalt/cu m} = \frac{(C \times V_a) - B}{V}$$

where:

- C = concentration ( $\mu\text{g}$  cobalt/ml) in the aliquot
- V<sub>a</sub> = volume of aliquot (ml)
- B = total  $\mu\text{g}$  of cobalt in the blank
- V = volume of air sampled (cu m)

IX. TABLES

TABLE IX-1

ESTIMATED WORKER EXPOSURE TO COBALT

Substance	No. of Workers Exposed*
Cobalt metal	235,000
Cobalt oxides	867,000
Cobalt drier**	301,000
Cobalt paste drier**	8,300
Cobalt naphthenate	79,000
Cobalt neodecanoate	1,300
Cobalt octanoate	8,100
Cobalt tallate	19,000
Cobalt titanate	900
Cobaltous acetate	21,000
Cobaltous carbonate	5,100
Cobaltous chloride	10,000
Cobaltous nitrate	8,600
Cobaltous oxalate	1,700
Cobaltous sulfate	8,300
Cobalt cyanide	7,200
Cobalt hydroxide	2,500
Cobalt 2-ethylhexoate	3,900

\*Many of these workers would be potentially exposed to only small amounts of cobalt through inhalation, ingestion, or dermal contact. The exposure estimates are not additive, since some workers would be exposed to more than one compound.

\*\*Substance(s) comprising the drier were not identified.

From the NIOSH National Occupational Hazard Survey, 1972-74 [313]

TABLE IX-2

## EFFECTS OF WORKPLACE EXPOSURE TO COBALT-CONTAINING SUBSTANCES

Substance(s) and Composition (if known)	Concentration (mg cobalt/cu m)	Duration, Years	No. of Workers	Effect	Reference No.
Cobalt metal	*	2-5	7	Respiratory irritation; no evidence of fibrosis	51
"	*	7	1	Marked pulmonary fibrosis resulting in death; elevated cobalt levels in lungs	50
"	*	12.5 (av.)	120	1 case of increased pulmonary reticulations	52
"	*	4	1	Death from cardiac insufficiency; elevated cardiac levels of cobalt	311
"	*	*	6	No evidence of pulmonary damage	34
Cobalt oxide	*	15-20	*	Chronic bronchitis and respiratory insufficiency	52
Cobaltous oxide	1-303 (av. 106)	*	247	Pulmonary changes in 8 (3.2%)	35
or Tungsten carbide, cobalt	0.8-12				
Tungsten carbide 95.9-97.6%, cobalt 2.4-4.1%	0.05-0.14	4.4 (av.)	1,802	Abnormal lung radiographic findings in 13 (0.8%)	37
Tungsten carbide 75-96%, cobalt 4-25%	0.6-25	1-13 (av. 6)	193	Lung radiographic changes in 31 (16%); spirometric abnormalities in 25 of 116 (22%)	33
Tungsten carbide, cobalt 6-11%	*	61.3% for 1-5, 37.1% for 5	62	Chronic bronchitis in 5 (8.1%); decreased vital capacity in 9 (14.5%)	29
Tungsten carbide, titanium carbide, cobalt 4.3-8.4%	0.043-0.57 (av. 0.21)	3-26	305	Lung radiographic changes in 56 (18.4%)	34

TABLE IX-2 (CONTINUED)

## EFFECTS OF WORKPLACE EXPOSURE TO COBALT-CONTAINING SUBSTANCES

Substance(s) and Composition (if known)	Concentration (mg cobalt/cu m)	Duration, Years	No. of Workers	Effect	Reference No.
Tungsten carbide, titanium carbide, cobalt 10%	*	0.5-4	27	Bronchitis in 11 (41%), pneumo- coniosis in 9 (33%), radiographic lung changes in 8 (30%)	11
Tungsten carbide, cobalt	0.007-0.19	5-16	29	Well-established fibrosis in 3, labored breathing in 11	24 25
"	0.1-0.2	(av. 6)	200-300	Pneumoconiosis in 3	23
"	*	14	1	Pulmonary fibrosis; tungsten, nickel, and titanium found in lungs	17
"	*	17	1	Well-established pulmonary fibrosis	21
"	0.045-0.47 (av. 0.22)	1-30 (av. 11)	22	No radiographic evidence of pulmonary fibrosis; possible reduction of vital capacity	40
"	0.03-0.56 (av. 0.24)	6	1	Well-established pulmonary fibrosis	20
"	*	9	1	"	15
"	0.6-3.2	(up to 3)	178	Pulmonary irritation in 50%	46
"	*	5	1	Well-established pulmonary fibrosis; titanium found in lungs	19
"	0.4-3.3	*	117	Chronic bronchitis in 35 (30%); mild fibrosis in 33 (28.2%)	35
"	*	2-8	3	Pulmonary fibrosis in one lung biopsy specimen	12
"	*	0.08-28 (av. 12.6)	1,500	Pulmonary fibrosis in 9 (0.6%)	26 27
"	0.03-0.3	1-14 (av. 5.8)	10	Mild fibrosis	13

TABLE IX-2 (CONTINUED)

## EFFECTS OF WORKPLACE EXPOSURE TO COBALT-CONTAINING SUBSTANCES

Substance(s) and Composition (if known)	Concentration (mg cobalt/cu m)	Duration, Years	No. of Workers	Effect	Reference No.
"	0.006-1.3	30% for <10, 44% for 10-20, 26% for >20	61	Pulmonary changes in 30	30
"	*	*	1	Asthma-like labored breathing	47
"	*	9	1	Marked fibrosis and emphysema; cobalt and other metals found in lung	15
"	*	8	1	"	16
"	*	*	5	Asthma-like labored breathing	26 27
"	*	1.5	1	"	14
Tungsten carbide/oxide, titanium, cobalt	0.4-2.9	*	178	Respiratory irritation in 73 (41%); bronchitis with labored breathing in 2	36
Tungsten carbide, titanium carbide, niobium, cobalt	*	0.08-9	100	Pulmonary irritation in 15 subjects; progressing to fibrosis in 5	28
Tungsten carbide, titanium, cobalt	*	6	1	Well-established pulmonary fibrosis	18
Tungsten carbide, titanium carbide, cobalt	*	*	200-250	6-10% with labored breathing; radiographic changes in 4%	38
Hard-metal tool manufacturing	* *	16-50 (av. 36)	12	Well-established pulmonary fibrosis	14
Welding fumes	*	15 (2 h/d)	1	Well-established pulmonary fibrosis; cobalt, chromium, nickel, and iron found in lung tissue	22

\*Data not reported

TABLE IX-3  
CHEMICAL AND PHYSICAL PROPERTIES OF COBALT AND SELECTED COBALT COMPOUNDS

Compound	Molecular Formula	Formula Weight	Melting Point (C)	Density	Solubility (g/100 cc)	
					H2O	Other Solvents
Cobalt	Co	58.933	1,495	8.9	--	Acid
Cobaltous acetate tetrahydrate	Co(C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> ) <sub>2</sub> ·4H <sub>2</sub> O	249.08 (-4H <sub>2</sub> O, 177.03)	-4H <sub>2</sub> O, 140	1.705 (19 C)	--	Dilute acids, alcohol pentyl acetate
Cobaltic acetyl-acetate	Co(HC(COCH <sub>3</sub> ) <sub>2</sub> ) <sub>3</sub>	356.26	241	1.43 (15 C)	--	--
Cobaltous carbonate (sphaerocobaltite)	CoCO <sub>3</sub>	118.94	Decomposes	4.13	--	Acid
Basic cobaltous carbonate	2CoCO <sub>3</sub> ·3Co(OH) <sub>2</sub> ·2H <sub>2</sub> O	534.74	--	--	Decomposes in hot	Acid, (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub>
Cobaltous chromate	CoCrO <sub>4</sub>	174.93	--	--	Decomposes in hot	Mineral acids, NH <sub>4</sub> OH
Cobaltous citrate	Co <sub>3</sub> (C <sub>6</sub> H <sub>5</sub> O <sub>7</sub> ) <sub>2</sub> ·2H <sub>2</sub> O	591.04	-2H <sub>2</sub> O, 150	--	0.8 in cold	Dilute acids
Cobaltous cyanide dihydrate	Co(CN) <sub>2</sub> ·2H <sub>2</sub> O	147.00	-2H <sub>2</sub> O, 280 (decomposes at 300)	Anhydrous 1.872 (25 C)	0.00418 in cold	KCN, HCl, NH <sub>4</sub> OH
Cobaltous formate	Co(CHO <sub>2</sub> ) <sub>2</sub> ·2H <sub>2</sub> O	185.00	-2H <sub>2</sub> O, 140 (decomposes at 175)	2.129 (22 C)	5.03 in cold	--
Cobalt halides:						
Cobaltous bromide	CoBr <sub>2</sub>	218.75	678 (under HBr and N <sub>2</sub> )	4.909	66.7 (59 C), 68.1 (97 C)	77.1 alcohol, 58.6 methanol; acetone, ether, methyl acetate
Cobaltous chloride	CoCl <sub>2</sub>	129.84	735	3.356 (25 C)	45 (7 C), 105 (96 C)	54.4 alcohol, 8.6 acetone, 38.5 meth- anol, slightly soluble, ether, glycerol, pyridine

TABLE IX-3 (CONTINUED)

## CHEMICAL AND PHYSICAL PROPERTIES OF COBALT AND SELECTED COBALT COMPOUNDS

Compound	Molecular Formula	Formula Weight	Melting Point (C)	Density	Solubility (g/100 cc)	
					H2O	Other Solvents
Cobaltous fluoride	CoF2	96.93	ca 1,200	4.43 (25 C)	1.5 (25 C) (decomposes in hot)	Warm mineral acids
Cobaltic fluoride	CoF3	115.93	--	3.88	Decomposes to Co(OH)3	--
Cobaltous iodide	CoI2	312.74	515 (in a vacuum)	5.68	159 (0 C) 420 (100 C)	Alcohol, acetone
Cobaltous hydroxide	Co(OH)2	92.95	Decomposes	3.597 (15 C)	--	Acids, NH4 salts
Cobaltic hydroxide	Co(OH)3 (Co2O3.3H2O)	109.96 (219.91)	-- Decomposes	-- 4.46	--	Acids
Cobaltous linoleate	Co(C18H31O2)2	617.83	--	--	--	Alcohol, ether, acetone
Cobaltous naphthenate	A mixture of many cobalt naphthenates that have varying chain lengths	--	--	--	--	Alcohol, ether, oil
Cobaltous nitrate	Co(NO3)2	182.96	Decomposes 100-105	2.49	--	Most organic solvents
Cobaltous oleate	Co(C18H33O2)2	621.86	235	--	--	Alcohol, ether, oils, benzene
Cobaltous oxalate	CoC2O4	146.95	Decomposes 250	3.02 (25 C)	--	Acid, NH4OH
Cobalt oxides:						
Cobaltous oxide	CoO	74.93	1,935	6.45	--	Acid, alkali
Cobaltic oxide	Co2O3	165.86	Decomposes 895	4.81-5.60	--	Acid

TABLE IX-3 (CONTINUED)

## CHEMICAL AND PHYSICAL PROPERTIES OF COBALT AND SELECTED COBALT COMPOUNDS

Compound	Molecular Formula	Formula Weight	Melting Point (C)	Density	Solubility (g/100 cc)	
					H2O	Other Solvents
Cobaltous cobaltic oxide	Co3O4	240.80	Transition point to CoO 900-950	6.07	--	Alkalis, acids
Cobaltous phosphate	Co3(PO4)2	366.74	--	2.587 (25 C)	--	H3PO4, NH4OH
Cobalt monosilicide	CoSi	87.03	1,395	--	--	HCl
Cobalt disilicide	CoSi2	115.11	1,277	5.3	--	--
Dicobalt monosilicide	Co2Si	145.95	1,327	7.28 (0 C)	--	Decomposes in acid
Cobaltous sulfate	CoSO4	155.00	735	3.472	36.2 (20 C) 83 (100 C)	1.04 (18 C) methanol
Cobaltous sulfide	CoS	91.00	1,116	5.45 (18 C)	0.00038 (18 C)	Slightly soluble acids
Cobalt disulfide	CoS2	123.06	--	4.269	--	HNO3, aqua regia
Cobaltic sulfide	Co2S3	214.06	--	4.8	--	Decomposes in acid, aqua regia
Cobalt tallate	Cobalt derivative of refined tall oil - of varying composition	--	--	--	--	--
Cobalt thiocyanate	Co(SCN)2	175.10	-3H2O, 105	--	--	Alcohols, ether, acetone, CHCl3
Cobaltous tungstate	CoWO4	306.78	--	8.42	--	Hot concentrated slightly soluble dilute acid

Adapted from references 2,247,312

TABLE IX-4

## SIMPLE COBALT SALTS, ORGANIC AND INORGANIC

CAS NO.	NAME	CAS NO.	NAME	CAS NO.	NAME
71-48-7	cobaltous acetate	11114-55-9	alloy;Al, Co	14640-56-3	cobalt pyrophosphate
136-52-7	cobalt 2-ethylhexanoate	12006-78-9	cobalt boride	14666-94-5	cobalt oleate
513-79-1	cobaltous carbonate	12013-10-4	cobalt sulfide (CoS <sub>2</sub> )	14666-96-7	cobalt linoleate
542-84-7	cobaltous cyanide	12016-80-7	cobalt hydroxide oxide	14965-99-2	cobaltic cyanide
544-18-3	cobaltous formate	12017-01-5	Co, Ti oxide (CoTiO <sub>3</sub> )	15238-00-3	cobaltous iodide
814-89-1	cobaltous oxalate	12017-12-8	cobalt silicide	18718-10-0	cobaltous phosphate (2:1)
866-81-9	cobaltous citrate	12017-13-9	cobalt telluride	21041-93-0	cobaltous hydroxide
932-69-4	cobalt benzoate	12017-38-8	Co, Ti oxide (Co <sub>2</sub> TiO <sub>4</sub> )	26490-63-1	cobalt tetrafluoroborate
1307-96-6	cobaltous oxide	12017-68-7	Co; compd. with Sm (5:1)	27016-73-1	cobalt arsenide
1307-99-9	cobalt selenide	12044-42-7	cobaltous arsenide	27253-31-2	cobalt neodecanoate *
1308-04-9	cobaltic oxide	12045-01-1	cobaltous boride	34262-88-9	cobalt terephthalate
1308-06-1	cobaltous cobaltic oxide	12052-28-7	Co, Fe oxide	37261-99-7	alloy; WC 88, Co 12
1317-42-6	cobalt sulfide (CoS)	12052-42-5	cobalt antimonide	38582-17-1	cobalt cyclohexanebutanoate
1333-88-6	Al, Co oxide	12134-02-0	cobalt phosphide	42978-77-8	cobalt methylbenzoate
1345-19-3	cobalt tin oxide	12214-13-0	Ce, compd. with Co (1:5)	49676-83-7	cobalt; 3,5,5-trimethylhexanoate
3017-60-5	cobalt thiocyanate	12256-04-7	cobaltic arsenide	53219-02-6	alloy; Co 9.9-90, Al 9.8-90
6700-85-2	cobalt octanoate	12263-08-0	cobalt molybdophosphate	58197-53-8	cobalt, 2-propionate
7440-48-4	cobalt	12774-15-1	alloy; WC 94, Co 6	58591-45-0	co, Ni oxide
7646-79-9	cobaltous chloride	13455-25-9	cobaltous chromate	67801-57-4	cobalt; 1,2,4-benzenetricarboxylate
7789-43-7	cobaltous bromide	13455-31-7	cobaltous perchlorate	67952-53-8	cobalt; 2-methyl 2-propionate
10026-17-2	cobaltous fluoride	13455-36-2	cobaltous phosphate	68016-03-5	molybdic acid; Co, Ni salt (2:1:1)
10026-18-3	cobaltic fluoride	13596-21-9	cobaltous phosphate	68123-03-5	cobalt, 4-aminobenzoate
10101-58-3	cobaltous tungstate	13762-14-6	cobalt molybdate (1:1)	68647-47-2	cobalt molybdate (1:3)
10124-43-3	cobaltous sulfate	14017-41-5	cobalt sulfamate	69011-09-2	Co, Zr oxide
10141-05-6	cobaltous nitrate	14590-13-7	cobaltous ammonium phosphate	12190-79-3	Co, Li oxide
				13586-84-6	cobalt octadecanoate

\*Alternate CAS No. of 52270-44-7

TABLE IX-5

## ORGANOCOBALT COMPLEXES AND COMPLEX COBALT SALTS

CAS No.	Molecular Formula	CAS No.	Molecular Formula
3252-99-1	C8-H14-Co-N4-04	49651-10-7	C42-Br2-Co-P2
3317-67-7	C32-H16-Co-N8	51084-32-3	C9-H8-04.1/2Co
10210-68-1	C8-Co2-08	51839-24-8	C2-H6-Co5-012.H2O
10534-89-1	C1.1/2C0-H18-N6	52729-67-6	C32-H15-Co-N8-03-S.Na
12602-23-2	C2-H6-Co-012	62207-76-5	C16-H12-Co-F2-N2-02
12715-61-6	C32-H30-Co-N8-010-S2	67875-38-1	C32-H15-C1-Co-N8-02-S
13408-73-6	C6-H24-Co-N6.3C1	67906-18-7	C6-H20-Co-N4.2C2-Au-N2
13586-82-8	C8-H16-02.xCo	68133-85-7	C4-H5-Co-N-04
13859-51-3	C1-Co-H15-N5.2C1	68189-40-2	C32-H14-C12-Co-N8-04-Se
13869-30-2	C4-H5-Co-N-04	68239-56-5	(C10-H18-Co-N2-04)x
14024-48-7	C10-H14-Co-04	68239-58-7	(C6-H12-C12-Co-N2)x
14123-08-1	C6-Co-N6.3/2Co	68475-45-6	C14-H26-Co-016
14126-32-0	C36-H30-Br2-Co-P2	68958-90-7	C4-H16-Co-N4.2C2-Au-N2
14931-83-0	C10-H12-Co-N2-08	69140-59-6	C2-H8-07-P2.Co.2K
21679-46-9	C15-H21-Co-06	69140-60-9	C2-H8-07-P2.Co.2Na
25971-15-7	C26-H38-Co2-N10-08	69178-34-3	C2-H8-07-P2.Co.2H3-N
29383-29-7	C32-H14-Co-N8-06-S2.2H	69178-42-3	C34-H32-Co-N8-010-S2
30638-08-5	C32-H15-Co-N8-03-S.H	69198-43-2	C48-H54-Br2-Co-P2
40621-10-1	C12-H23-P-S2.1/2Co		

TABLE IX-6

## SUBSTANCES OF UNIDENTIFIED STRUCTURE

CAS No.	Description
1345-16-0	Cl pigment blue 28
5931-89-5	cobalt acetate
8011-87-8	Cl pigment green 19
11104-61-3	cobalt oxide
12653-56-4	cobalt sulfide
12672-27-4	aluminum cobalt oxide
12737-30-3	cobalt nickel oxide
37367-90-1	cobalt borate
37382-24-4	chromium cobalt oxide
29261-75-6	cobalt zirconium oxide
61789-51-3	cobalt naphthenate
61789-52-4	fatty acids, tall-oil, Co salts
63497-09-6	chromium cobalt iron oxide
68130-37-0	Co, molybdenum hydroxide oxide phosphate
68152-91-0	tall oils, cobalt salt
68186-85-6	spinel; Co, Ti green
68186-86-7	spinel; Al, Co blue
68186-87-8	spinel; Al, Co, Zn blue
68186-89-0	periclase; Co, Ni gray
68186-97-0	spinel; Cr, Co, Fe black
68187-05-3	spinel; Co, Sn gray
68187-11-1	spinel; Al, Cr, Co blue green
68187-40-6	olivine, cobalt blue
68187-49-7	spinel; Cr, Co green
68187-50-8	spinel; Co, Fe black
68409-81-4	fatty acids, C6-19-branched, Co salts
68411-08-5	Co, dextrin complexes
68412-74-8	phenakite; Co, Zn blue
68442-96-6	hydrofluoric acid, reaction products with alumina and cobalt chloride
68457-13-6	Co, borate neodecanoate complexes
68457-90-9	zirconium, carbonate dipropylene glycol 2-ethylhexanoate isobutyl alcohol oxopropionate cobalt complexes
68478-57-9	Co, 2-ethylhexanoate isononate complexes
68478-58-0	Co, 2-ethylhexanoate 3,5,5-trimethylhexanoate complexes
68512-31-2	periclase, Co blue gray
68553-15-1	linseed oil; Co, Mn, salt
68584-96-3	2-naphthalene sulfonic acid, 6-hydroxy-5-nitroso; Co, Na salt; complex with vinylpyrrolidone polymer

TABLE IX-6 (CONTINUED)

## SUBSTANCES OF UNIDENTIFIED STRUCTURE

CAS No.	Description
68608-09-3	spinel; Al, Co, Sn
68608-93-5	boric acid; Co, Mg salt; red-blue
68609-02-9	Co, borate isononoate neodecanoate complexes
68610-13-9	phosphoric acid; Co, Li salt; violet
68784-10-1	CdS; solid soln. with ZnS, Al, Cu, and Co; Ag-doped
68855-86-7	fatty acids, tallow, hydrogenated, Co salts
68955-83-9	fatty acids, C9-13-neo-, Co salts
68956-82-1	resin acids and rosin acids, Co salts
68988-10-3	zirconium, dipropylene glycol, isobutyl alcohol, neodecanoate, propionate Co complexes
69012-37-9	slimes and sludges, Co terephthalate
69012-71-1	leach residues, Zn ore-calcine, Co repulp
69012-72-2	leach residues; Zn ore-calcine; Zn, Co
70131-61-2	cobalt salt of mixed polymer

X. FIGURES

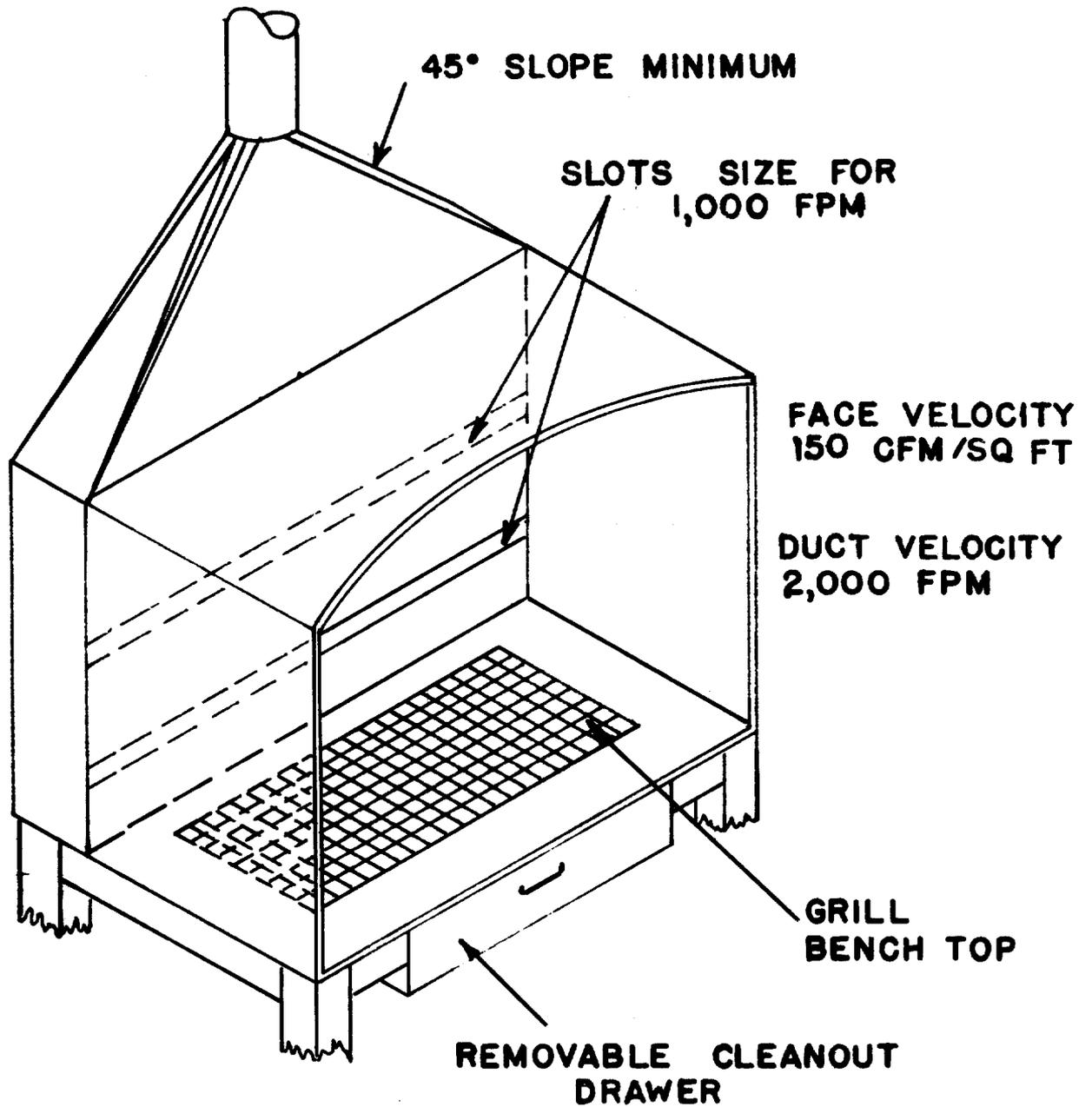


FIGURE X-1. EXHAUST BOOTH FOR PORTABLE GRINDING

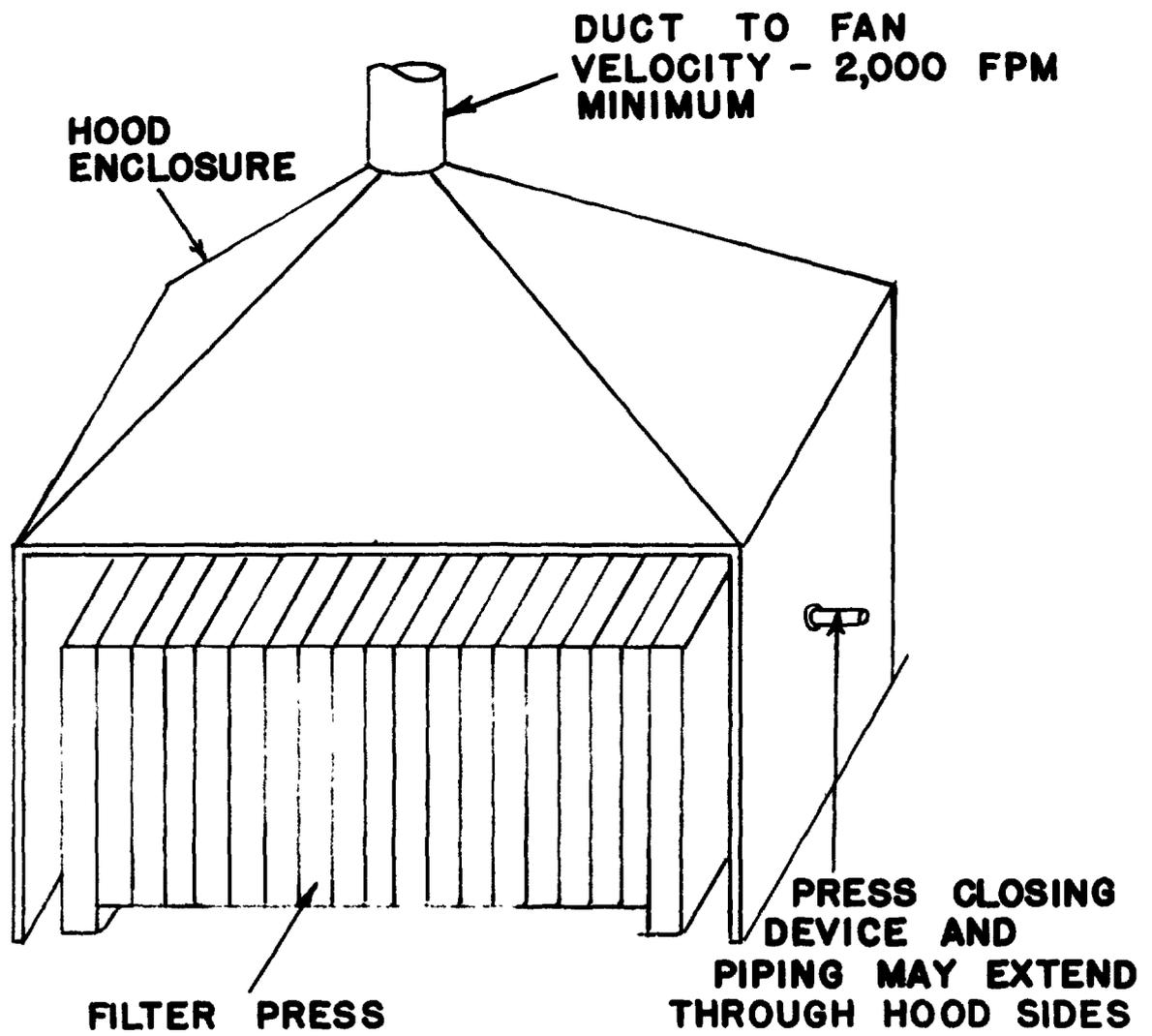


FIGURE X-2. ENCLOSURE FOR FILTER PRESSES

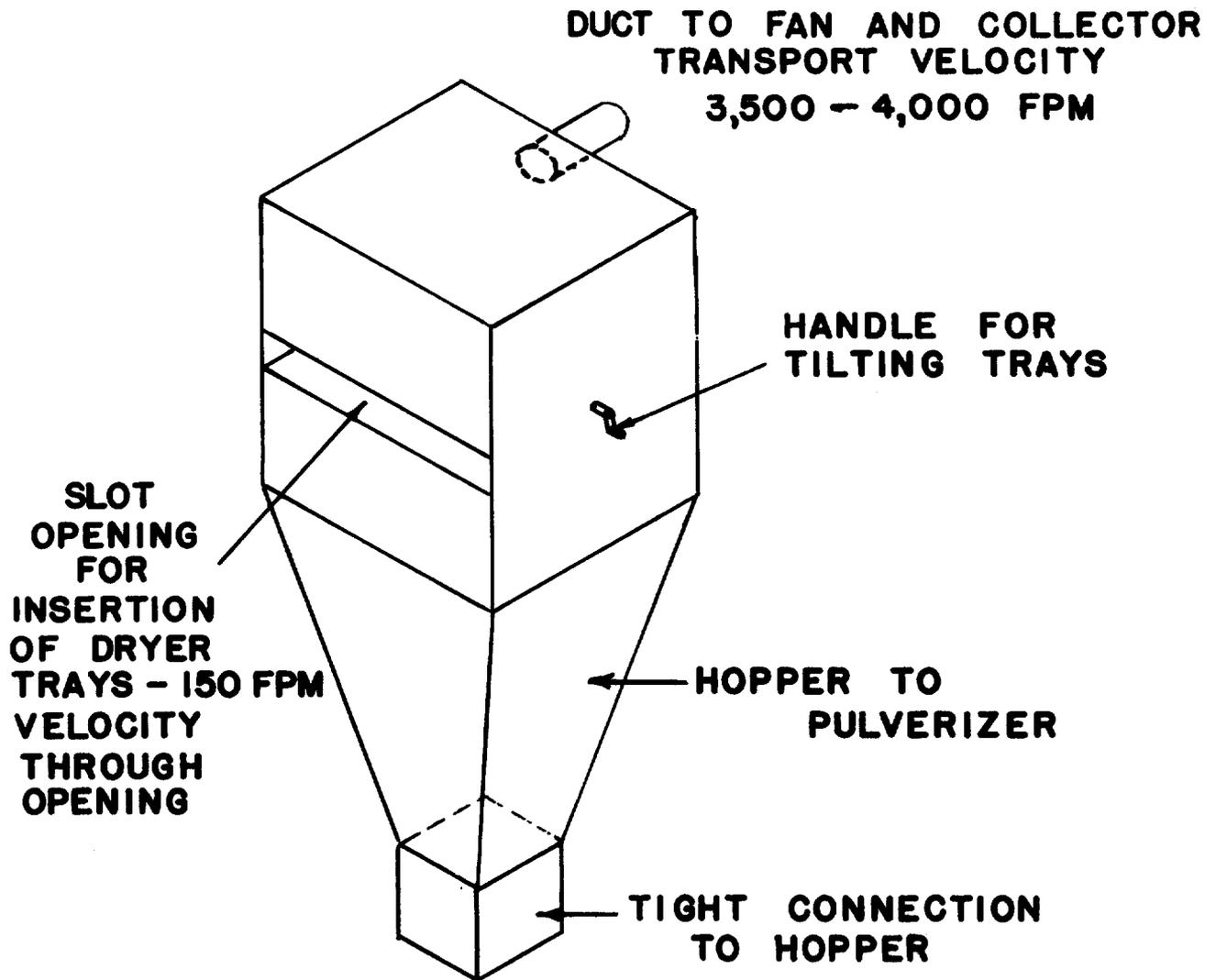


FIGURE X-3. ENCLOSURE FOR EMPTYING TRAYS OF CAKED POWDERS

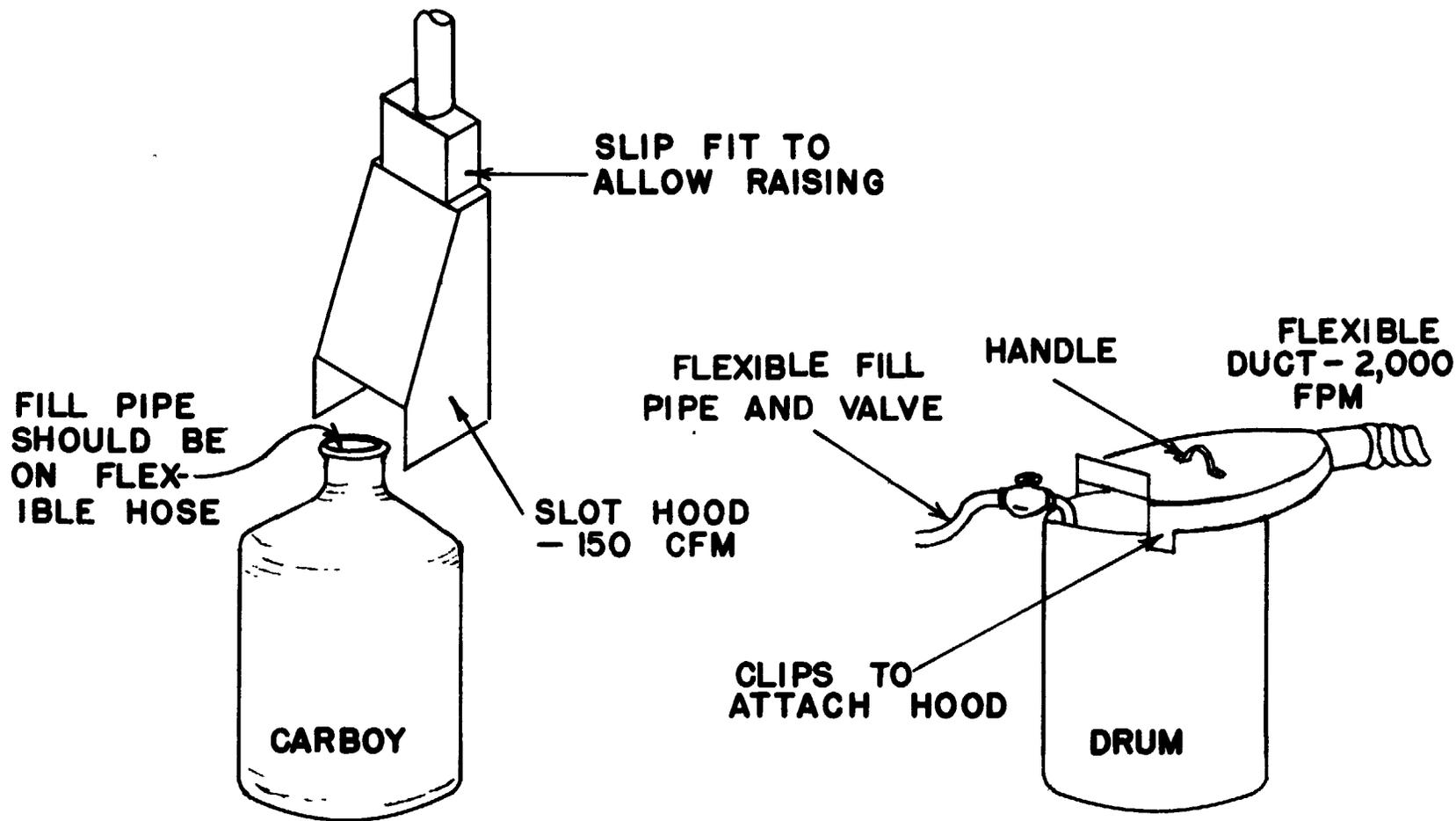


FIGURE X-4. TYPICAL ARRANGEMENTS FOR FILLING CONTAINERS

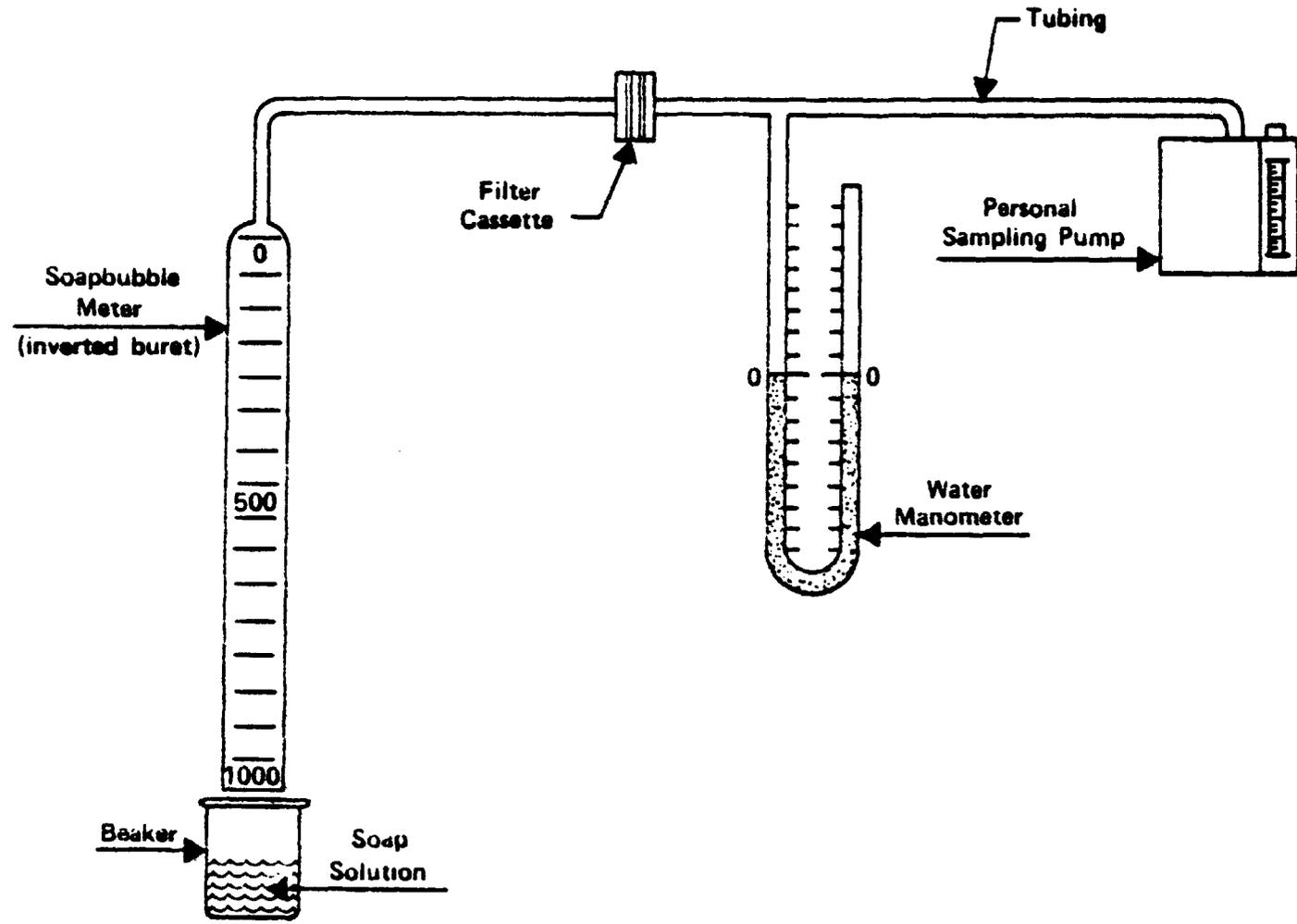


FIGURE X-5. CALIBRATION SETUP FOR PERSONAL SAMPLING PUMP WITH FILTER CASSETTE

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