DUSSAULT FOUNDRY
SOLID WASTE DISPOSAL AREA
CLOSURE PLAN

PREPARED BY
WENDEL ENGINEERS, P.C.

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Introduction

This plan will serve to develop and identify the steps and procedures proposed by Dussault Foundry for the Closure of the onsite waste foundry sand stockpile. This plan has been prepared at the request of the owner in order to comply with the requirements on NYSDEC Region 9 and Niagara County Health Dept. in resolving the concern of the previously stockpiled foundry sand.

Historical Review

Dussault Foundry is located on Washburn St. in the city of Lockport along the edge of the Niagara escarpment. The company has been operating a foundry operation at that faciliy since 1914. The area of concern is primarily located immediately east of the foundry buildings. It consists of a sand stockpile consisting of aproximately 20,100 cy exhibiting the contours as depicted on the attached drawing no. DUS-86-1.

Foundry sand is created when clean sand has been impregnated with resins to form molds and cores for the foundry operations. These sands account for nearly all foundry waste and where practicle can be recylcled a number of times thereby significantly reducing the total of landfill waste leaving the foundry. Dussault Foundry recycles approximately 90 % of all of the sand used during normal foundry operations. The weekly addition of approximately 15 - 20 tons of clean sand to recycled sand balances the foundry sand requiremnts. Conversely, a similar amount of sand is discarded from the molding process.

The typical flow cycle for materaials used in the molding process in foundry operations is detailed below:

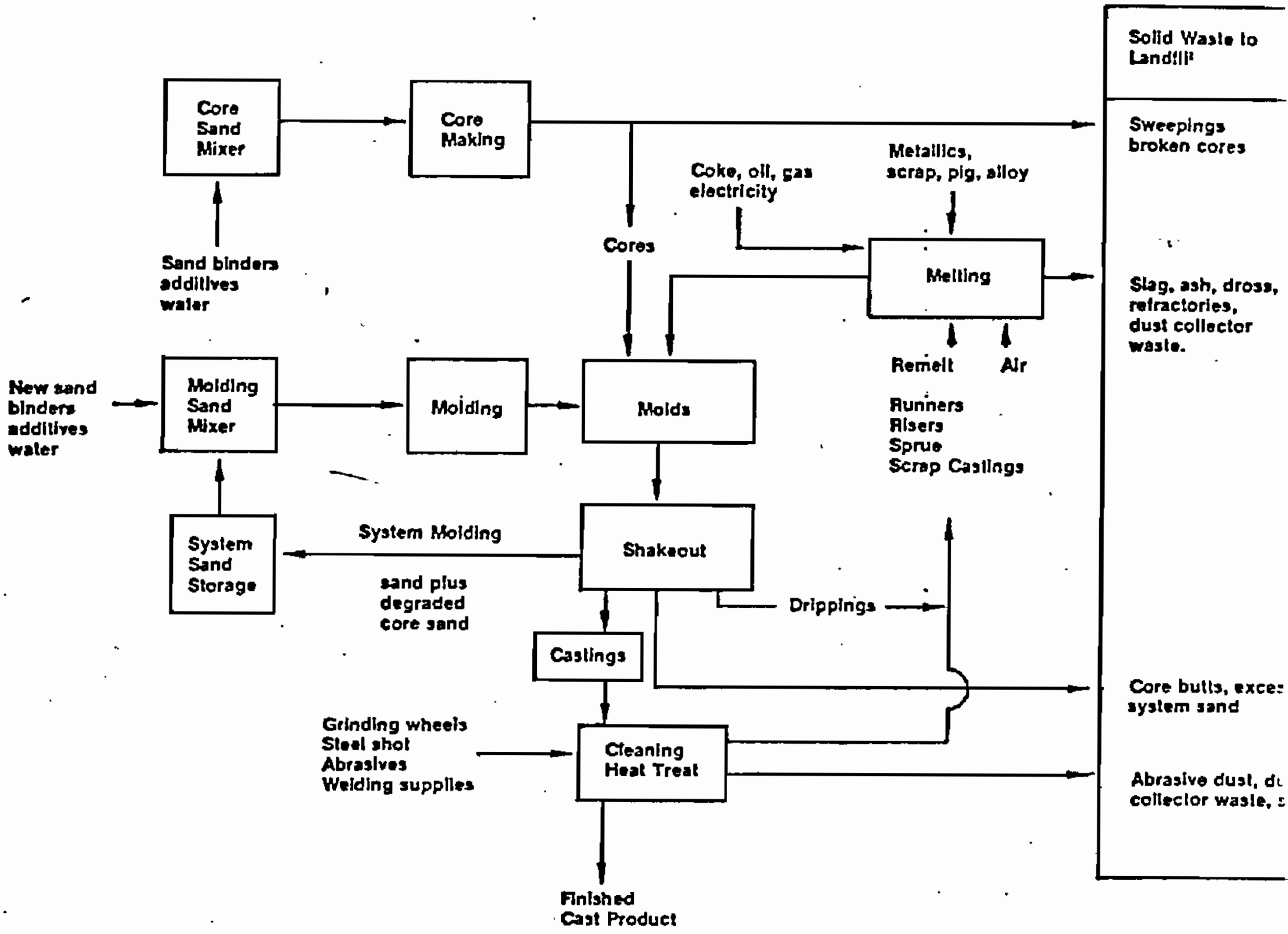


Fig. 1. Flow of materials in green sand foundry processing.

Coremaking and molding usually produce over 75% of the solid wastes generated by sand foundries. Melting operations generate most of the remainder with minor contributions from cleaning and heat treating processes and dust collectors.

Material Test Data

Dussault Foundry has over a period of years tested the foundry sand stockpiled at the facility. This information has been included as an appendex to this report. The most recent testing was conducted by Beak Consultants of Toronto at the direction of Wendel Engineers.

A composite sample was collected from the pile by a Wendel representative. Three individual samples from various depths were combined to form a composite sample of approximately 10 kg. This sample was hand delivered to Beak in Akron and analyzed for the parameter phenol. Review of the analytical data indicates that present levels of phenols in the sand are 20 ug/g, less than levels indicated in earlier test of July 1985, and February 1981 by AES. (see appendix)

Summary of Onsite Landfill Volumes

Survey of the existing pile as conducted on 10/86 indicated that approximately 20,100 cy of material existed in the onsite stockpile. The data was gathered using a Wild T-1000 Electronic Total Station and Maptech automated contour package.

A planimetric volume takeoff of the pile and review of test pit data indicated the limits of the closure operation. Excavation of the onsite material for transport to the approved disposal facility, Lockport Landfill, operated by Niagara County Refuse Disposal District will be initiated upon review and approval of this plan.

Evaluation of Cost Estimates

An estimate of closure cost for the removal of sands from the onsite storage pile to the Lockport Landfill facility has been completed. The total volume of sand from the storgae pile would approximate 1005 round trips to the disposal facility assuming a 20 cy truck was used for the material transfer. At present, Farley Trucking has been permitted under Part 364 Regulations to haul material from the site to the Landfill. Dussault Foundry will similarly permit their disposal truck to accommodate disposal of generated waste from the site as required.

As previously stated, approximately 1000 trips to the landfill is required to fulfill Dussaults disposal obligations. A a rate of $12.00 / trip, the total cost for disposal is estimated to be $12,000--$15,000.00. The cost of restoration of the disturbed area has been estimated at roughly $3,200.00, of which approximately $2,500 .00 would be used for the development of a compacted stone laydown area as indicated on Drawing Dus-86-2.

The balance,$ 700 .00 would be expended on the spreading of approximately 270 cy of topsoil over those disturbed areas that will not be incorporated into the stoned laydown area.

Closure of the Existing Disposal Area

Dussalult Foundry initiated removal of the sand in late September of this year. To date approximately 1,300 cy of material have been hauled to Lockport Landfill where it has been mixed with the onsite landfill cover material. By incorporating the sand into the cover, leachate encapsulation into each working cell will be reduced. The more permeable cover material allows leachate to migrate through the refuse down to the leachate collection system for removal and offsite treatment.

This disposal option is economically advantageous to both parties in that Dussault is accomplishing the required disposal while the Lockport Landfill is reducing the amount of daily cover that must be purchased to comply with their operating permit requirements.

It should be noted that all NYSDEC requirements for the disposal of an industrial waste at the facility have been met. The appropriate form, 47-19-7 has been included as an attachment to this report for informational purposes.

An additional positive effect of this disposal method is a neutralizing effect on the landfill leachate. As evidenced in the foundry sand leachate characterization in the following Table.

Table 25. Ranges of Pollutants in Selected Wastes

Component	Foundry Leachate	Urban Landfill Leachate	Septic Tank Effluent
Organic carbon (mg/l)	4-185	250-28,000	25-200
COD (mg/l)	25-1,100	100-51,000	250-1,000
Phenol (μg/l)	12-400	—	0-300*
Cyanide (μg/l)	20-80	—	—
Sulfate (mg/l)	30-1,200	25-1,500	10-600
Fluoride (mg/l)	3-120	—	0-10
Iron (mg/l)	0.1-0.5	200-1,700	0-20
Zn (mg/l)	0.1-15	1-135	0.15*
Ni (mg/l)	0-0.6	0.01-0.8	0.02
Cu (mg/l)	0.02-1.6	0.1-10	0.1*
pH	7.2-10.0	4-9	6.8-8.5

*Municipal wastewater effluents

Foundry leachate typically ranges in pH from 7.2 to 10, sanitary landfill leachate during early stages of aerobic digestion is in the 4.5 pH range. By creating a more favorable environment for aerobic degredation of the refuse, more complete digestion will ultimately reflect in lower methane generation .

Revegetation and Restoration

Once the foundry sand has been removed to the disposal facility, restoration of the disturbed areas will be initiated. A laydown area as indicated on drawing Dus-86-2 will be developed to provide laydown areas for forgings and castings. The entire area will be graded level and covered with approximately 6 inches of crushed stone. The remaining disturbed areas will be topsoiled and seeded using conservation seed mixes locally available at a rate of 40 lbs/ acre.

Trees and shrubs are expected to enter the area through natural progression. At present, there is sufficient screening from large trees to the north of the storage area to reduce any visual impacts of the removal and revegation/ restoration activities.

Long Term Material Disposal Options

Dussalut Foundry has purchased a waste sand hauling truck which will continue to remove waste material to the disposal facility on a regular basis. No waste material will be stored at the site. There will be a small covered area where sand will be temporarily stored for reuse in the molding process. This area will be constructed adjacent to an existing building, reference the attached sketch, and will reduce exposure to rain and snow, thereby eliminating the potential for leachate generation. Alternate permitted disposal sites will be evaluated should the Lockport facility not be granted a permit to expand.

Waste Material Handling Procedures

Dussault Foundry will routinely transfer waste material to the disposal facility with its permitted hauling truck. Waste sands from the foundry operation which cannot be recycled or reused in the molding process will be immediately loaded into this truck as it is generated, eliminating any future waste storage areas at the site.

PROPOSED SCHEDULE OF REMOVAL ACTIVITIES

ESTIMATED VOLUME OF STOCKPILE 10/86 - 20,100 CY

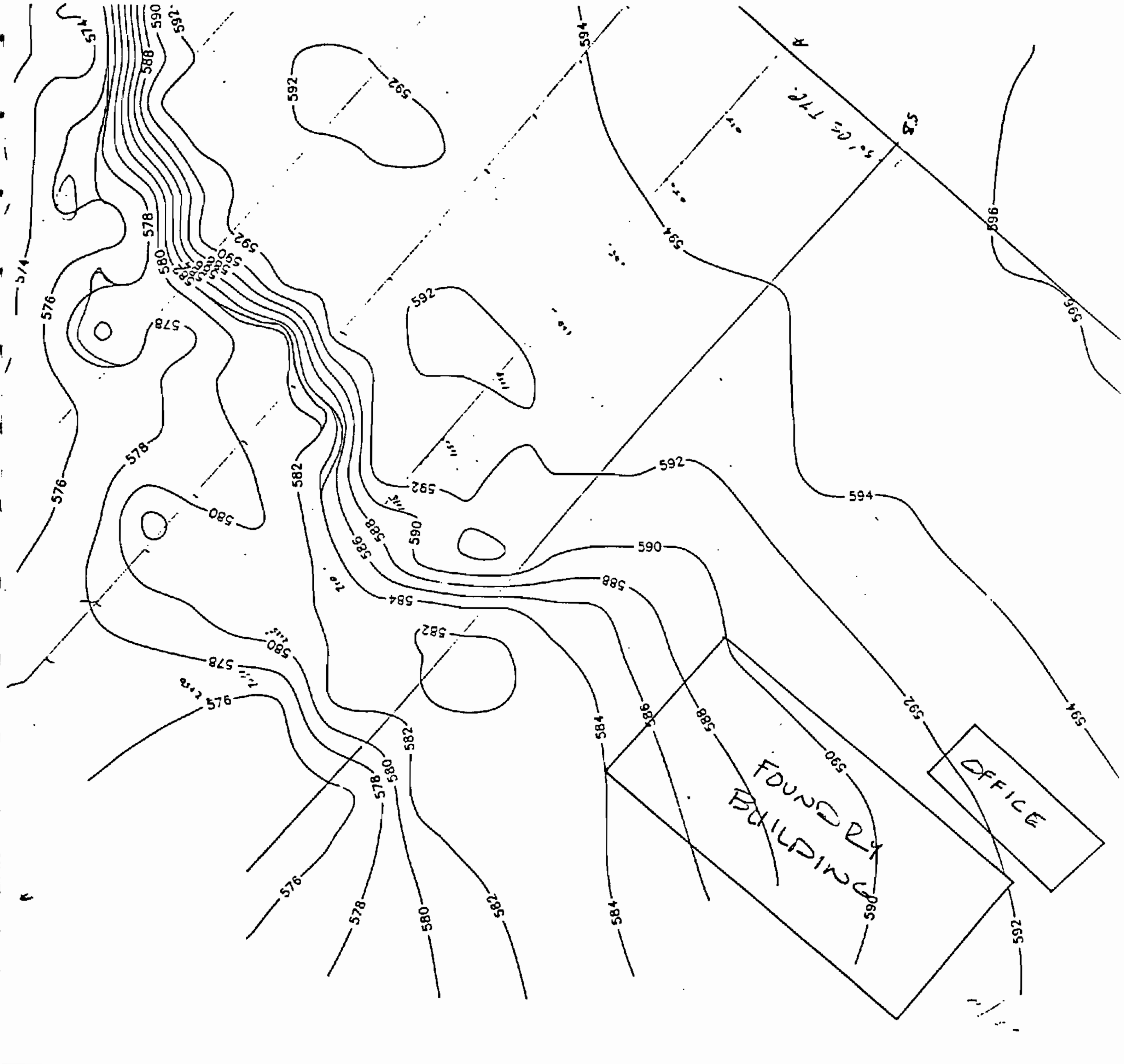
REMOVAL ESTIMATES/BY MONTH

Month/Yr.	Monthly Vols.	Round Trips Rqd.*
OCT. 86	2,000 CY	100
NOV. 86	2,000 CY	100
DEC. 86	2,000 CY	100
JAN. 87	2,000 CY	100
FEB. 87	2,000 CY	100
MAR. 87	2,000 CY	100
APRIL 87	2,000 CY	100
MAY 87	2,000 CY	100
JUNE 87	2,000 CY	100
JULY 87	2,000 CY	100

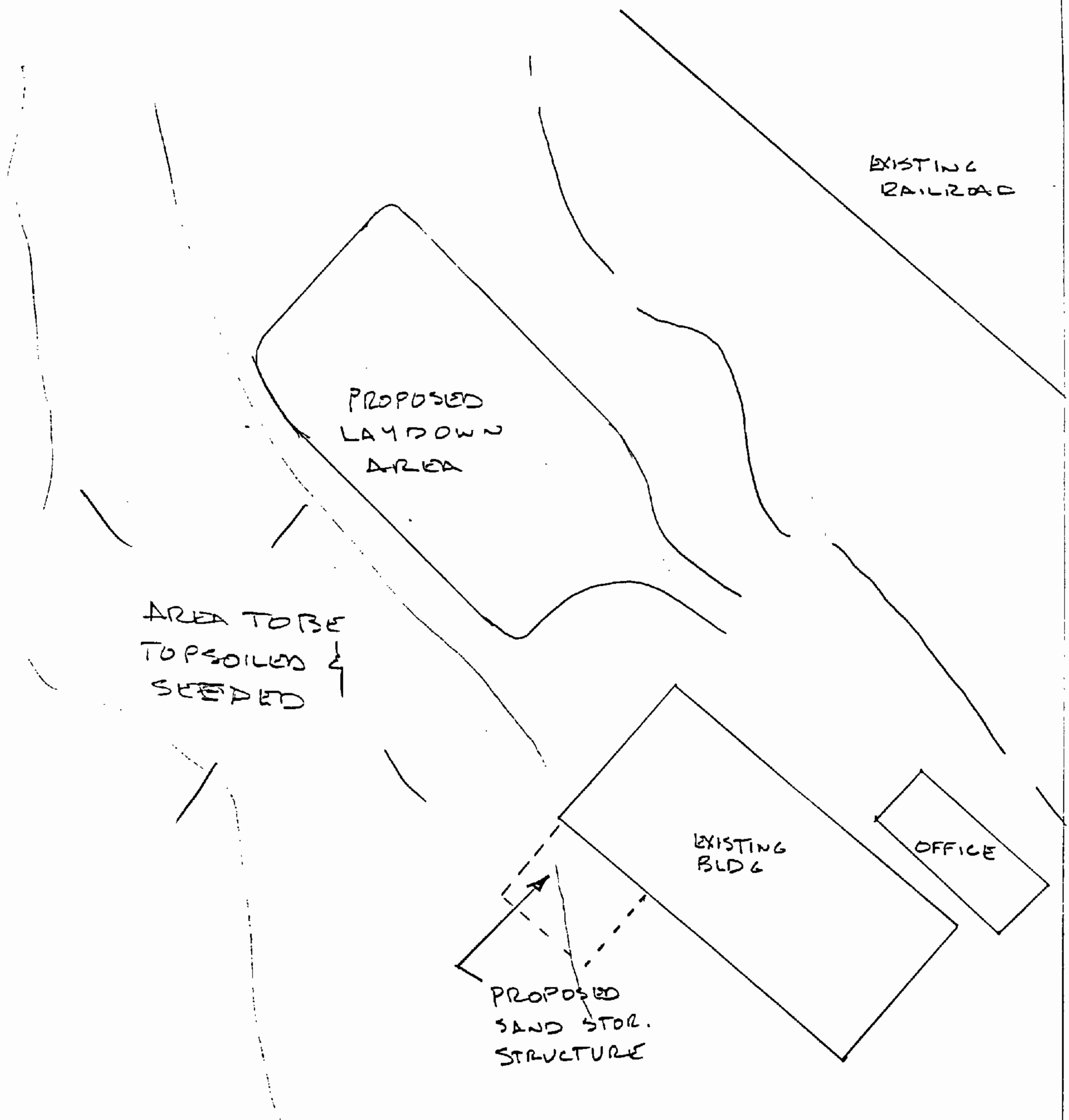
Additional hauling to remove sand being generated

* Estimates assuming 20 CY truck @ 15 trips per day. Rate @ 24/Hr at $192/day. Estimated 6.5/days/mo. required.

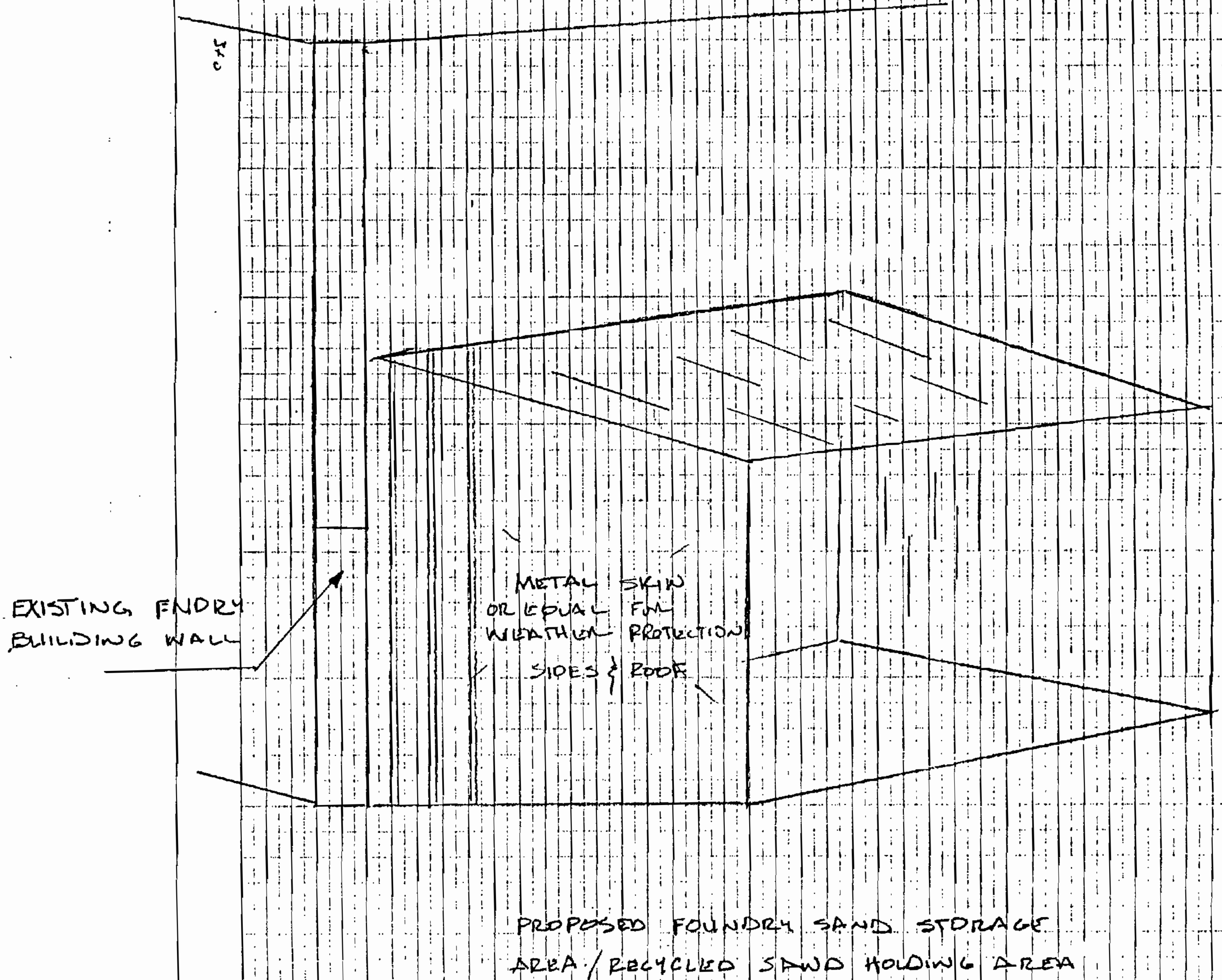
Total Estimated Fee <u>$12,480</u>



DUSSAULT FNDR
SAND STOCKPILE
CONTOURS 10/86
DWG: DUS-86-1



DUSSAULT FNDRY
RECLAMATION PLAN
DWG-DUS-86-2


3+0
EXISTING FNDRY BUILDING WALL
METAL SKIN OR EQUAL FOR WEATHER PROTECTION SIDES & ROOF
PROPOSED FOUNDRY SAND STORAGE AREA / RECYCLED SAND HOLDING AREA

47 19-9 (8/83)

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF SOLID AND HAZARDOUS WASTE

WASTE TRANSPORTER PERMIT APPLICATION—6 NYCRR Part 364

PART A—Applicant Information

1. APPLICANT BUSINESS NAME: DUSSAULT FOUNDRY

2. NYSDEC PERMIT NUMBER: ☐☐ — ☐☐☐

3. MAILING ADDRESS
STREET: 2 WASHBURN STREET
CITY: LOCKPORT
STATE: NY
ZIP CODE: 14094
COUNTY: NIAGARA

4. EPA ID NUMBER:

5. CONTACT PERSON: JAMES MAXWELL

6. PHONE NUMBER: (716) 433-3851

7. CHECK
☒ New Application ☐ Renewal ☐ Proof of Insurance Attached

8. PERMIT FEE ATTACHED
a. Regulatory:
b. UPA: 25.00
c. Other:
d. Total:

WASTE TRANSPORTER PERMIT APPLICATION—6 NYCRR Part 364

PART B—Vehicle Information

1. APPLICANT BUSINESS NAME (for Modifications only):

2. NYSDEC PERMIT NUMBER (For Modifications only): ☐☐ — ☐☐☐

3. VEHICLE FEE ATTACHED (for modification only)
a. Regulatory:
b. UPA:
c. Other:
d. Total:

4. TOTAL NUMBER OF VEHICLES: ONE

5. LOCATION WHERE VEHICLES ARE GARAGED:
STREET: 2 WASHBURN STREET
CITY: LOCKPORT
STATE: NY
ZIP CODE: 14094

6. License Number	7. State	8. Capacity	9. Units	10. Make	11. Type	12. Delete	13. Add
AK 8443	NY	14	02		Dump		

14. I hereby affirm under penalty of perjury that information provided on this form is true to the best of my knowledge and belief. False statements made herein are punishable as a Class A misdemeanor pursuant to Section 210.45 of the Penal Law.

SIGNATURE:

PRINTED OR TYPED NAME: James Maxwell

TITLE: President

DATE: October 23, 1986

47-19-10 (5/84)

NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DIVISION OF SOLID AND HAZARDOUS WASTE

WASTE TRANSPORTER PERMIT APPLICATION—6NYCRR Part 364

PART C—Waste Information

1. APPLICANT BUSINESS NAME: DUSSAULT FOUNDRY

2. NYSDEC PERMIT NUMBER: ☐☐ — ☐☐☐

3. TREATMENT, STORAGE, OR DISPOSAL FACILITY (TSDF) INFORMATION ☐ Delete ☐ Add

EPA ID Number:

NYSDEC Facility ID Number: 32S05

NAME: Niagara County Refuse Disposal District - Lockport Landfill

STREET: Richfield Street

CITY: Lockport

STATE: NY

ZIP CODE: 14094

CONTACT PERSON: Ken Moss

PHONE NUMBER: (716) 434-2638

WASTE INFORMATION

4. Waste Description	5. Waste Code	6. Form	7. Handling Method	8. Delete	9. Add
Non Hazardous - Foundry Sand	N823	02	090		
Solids/100% - No Liquids					

10. COMMENTS

A 47-19-7 has been approved by DEC Region 9 - for disposal of this material at this site.

11. STATEMENT OF OWNER OR OPERATOR OF TREATMENT, STORAGE OR DISPOSAL FACILITY

Permission is hereby granted to the above named applicant to deliver waste stated in this application to the T.S.D.F. listed above, subject to the Rules and Regulations of the Department of Environmental Conservation

SIGNATURE:

PRINTED OR TYPED NAME: James Maxwell

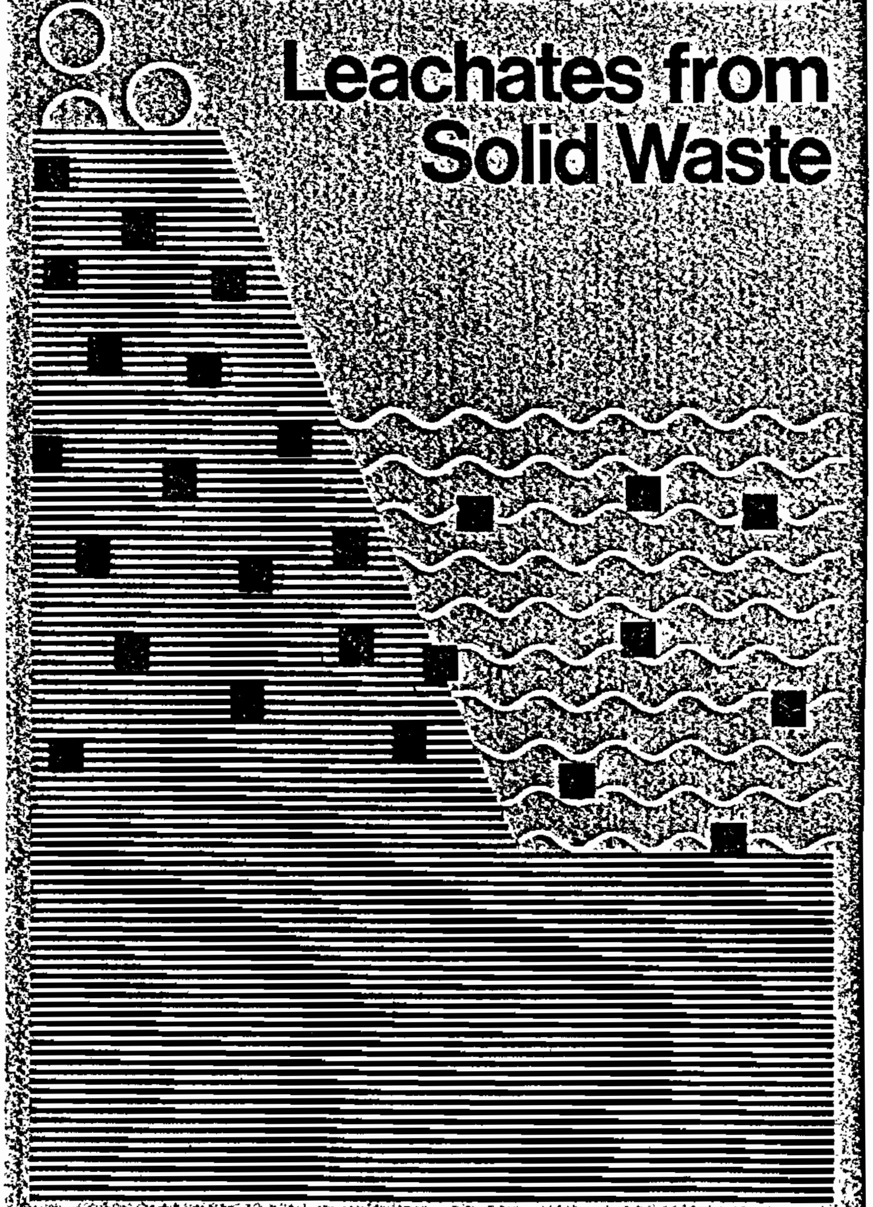
TITLE: President/Dussault Foundry

DATE: October 23, 1986

FOUNDRY LANDFILL

Leachates from Solid Waste

research report



american
foundrymen's
society
golf & wolf roads
des plaines, IL 60016

Preface

Early in 1972 the AFS Water Quality and Waste Disposal Committee (10-F) began assembling available data regarding foundry solid waste disposal and its potential effect on the environment. This detailed search revealed that little was actually known and that studies completed or studies to be undertaken in the future would not yield information the committee felt was necessary to provide adequate long-term guidance to the foundryman.

The committee defined the scope and parameters of a study that would yield maximum information within a reasonable time. For a program of this nature to succeed, the investigators needed detailed knowledge regarding foundry practices, sand control, metallurgy, solid waste disposal and water quality. The right proportion of each of these capabilities was found at the University of Wisconsin at Madison and the contents of this Research Report are ample testimony to both the thoroughness of the research and the invaluable guidance of the Monitoring Committee:

J. Goudzwaard, Chairman
C. H. Savery, Secretary
G. E. Calhoun
T. H. Davies
W. Dube
D. J. Jezwinski
F. W. Rohr
H. W. Ruf
C. E. Steinmetz
W. M. Throop
T. W. Wirth
W. B. Huelsen, AFS Staff

1

Solid Waste from Sand Foundry Processing

Foundries are major consumers of waste materials. Scrap iron and steel are a major source of raw materials, amounting to 85% or more of the 20-22 millions of tons of ferrous castings produced annually. Reclaimed copper, aluminum, lead, tin, zinc and other metals are also recycled to a major extent in making castings. The recycled cast product is everywhere evident in artifacts and machines of man's material civilization. In addition, other residues from manufacturing operations such as asphalts, pitches, sugars, resins and cellulose waste are used in the foundry processes.

While foundries consume and recycle metallic and other wastes, their processes also produce solid wastes which are presently not recycled and eventually find their way to solid waste landfill sites. This chapter deals with an overview of wastes from typical sand foundry processes that usually find their way to those landfills.

At landfills, the action of rain, snow and weather may permit water to percolate downward through these materials and leach water soluble constituents out of them. The leachate, so formed, may join groundwater, creeks or streams and possibly have water-polluting effects. This possibility, of course, is determined by the nature and quantity of leachable constituents and landfill materials.

Characterizing foundry wastes as to their origin, composition and potential for leachate formation becomes necessary to determine whether foundry waste landfills may contribute to waterpolluting effects upon the environment. Relating wastes to the foundry operations producing them and establishing the nature and proportion of components of the waste, which are present in landfill from typical foundries, is the purpose of this chapter. Questions relating to leachate formation from waste components of the aggregate material are covered in chapters 2-4, also developed from this research project.[12-13]

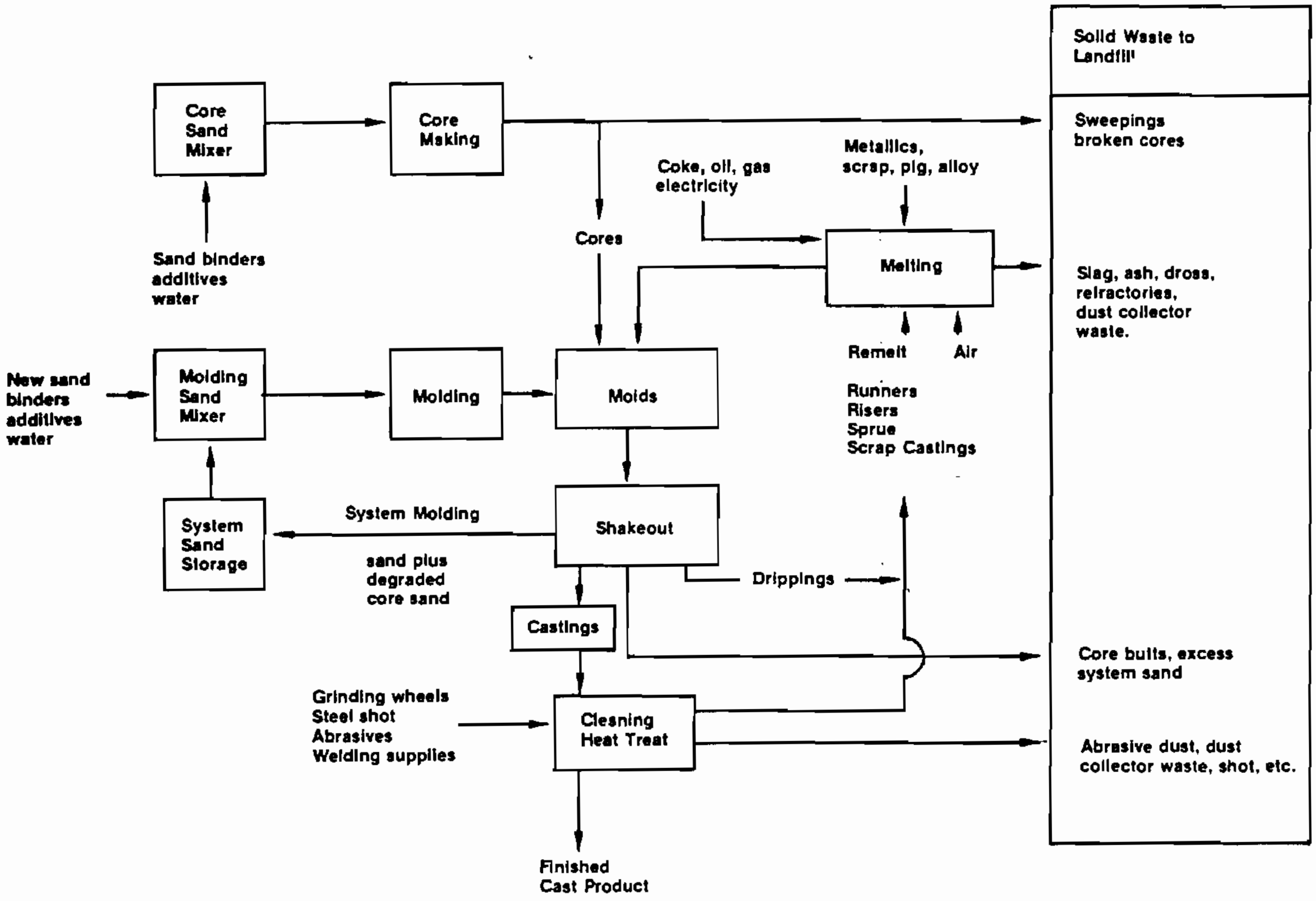


Fig. 1. Flow of materials in green sand foundry processing.

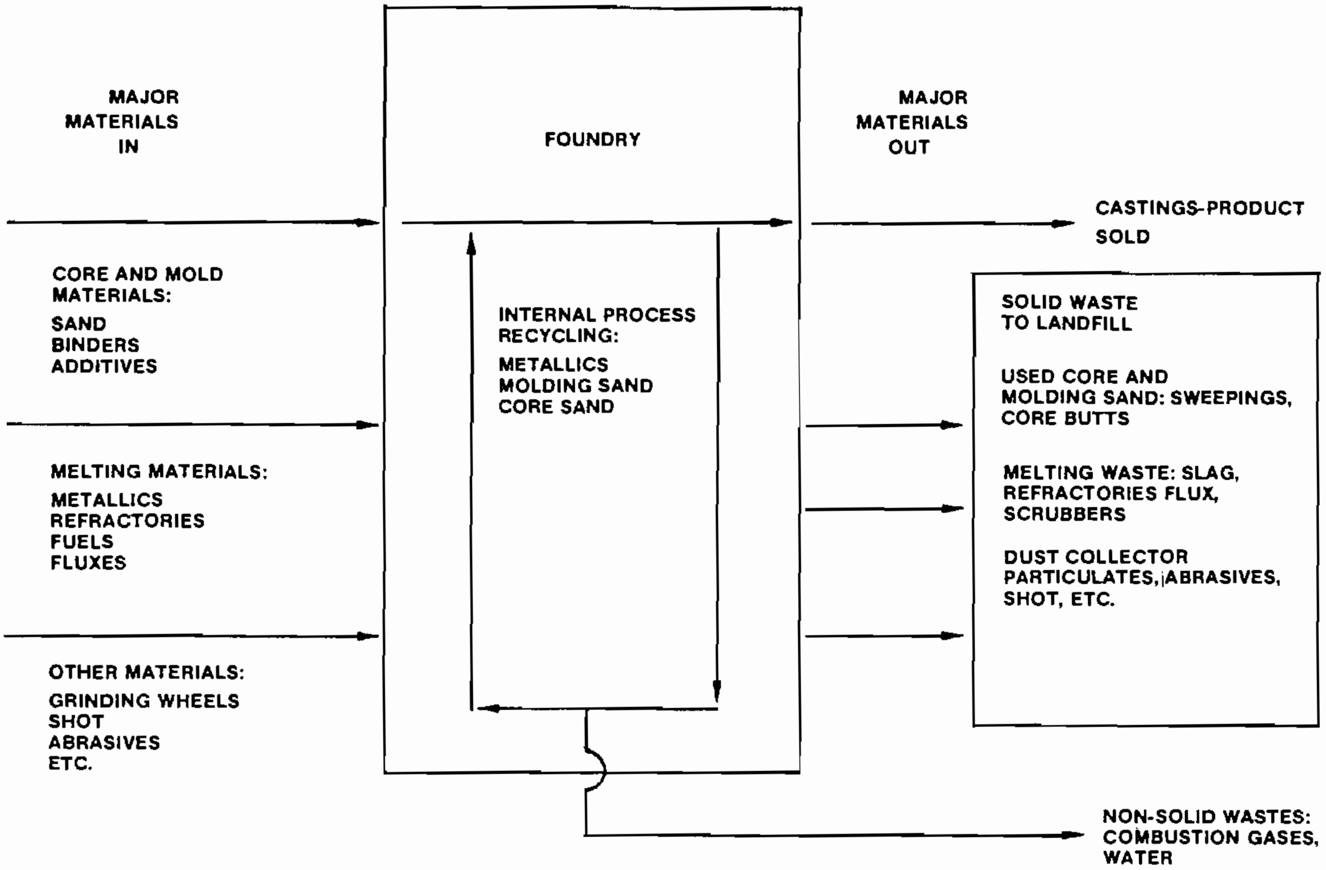


Fig. 2. Balance of major solid materials entering and leaving the sand foundry.

Generation of Solid Wastes and Material Balances in Foundries

Basic processing steps in the production of sand castings are coremaking, molding, melting and pouring, and cleaning and inspection.[4] A schematic diagram of flow of materials in the processes and finally to the solid waste stream, is shown in Fig. 1.

Coremaking and molding usually produce over 75% of the solid wastes generated by sand foundries. Melting operations generate most of the remainder with minor contributions from cleaning and heat treating processes and dust collectors.[1-3] Other investigations have verified these conclusions.[5,6]

Solid waste originates in the balance between incoming and outgoing materials, including product, in a foundry operation, Fig. 2. Aside from the cast product, the only solid materials leaving a ferrous foundry are landfill wastes. Nonferrous foundries, however, generate additional metallic wastes in the form of dross and grinding residues. These are returned to smelters for metal reclamation. The refined material is returned to the foundry as ingot, thereby reducing metal loss.

Quantities and kinds of materials entering a foundry are known from purchasing records. Materials leaving a foundry can be weighed to determine a quantitative materials balance based on Fig. 2. Also, quantities of material entering each process can be determined so that amounts of material undergoing chemical and thermal processing reactions can be known. Thus, the quantity and qualitative chemical analysis of each type of process waste going to landfill can be determined with a materials balance.

Material balances have been determined on seven foundries. Foundry I is a malleable iron operation using induction melting. Foundry II produces gray and ductile iron using basic practice cupola melting. Foundry III is a copper alloy operation that is a special case because its core and molding sand was used only once while all others recycled their molding sand. Foundry IV is another gray and ductile iron operation using a cupola for primary melting and duplexing into induction furnaces. Foundry V is a steel-casting operation using direct arc furnaces. Foundry VI is an aluminum foundry using crucible melting and making most of its molds with core sands. Foundry VII, another copper alloy foundry, uses crucible and induction melting and has a high percentage of cores in its molds.

All seven foundries use green sand molding. A variety of coremaking processes were used. In each case, total weights of new material purchases and total weight of wastes sent to landfill were determined on an annual basis for this research.

Materials entering foundry processes were divided into several categories, depending on their usage and purpose in the various processes. The categories into which new materials were divided were:

Refractories
*System sand for molding
  Silica and other aggregates
    Clays
    Carbon (or other additives)
  *Core sands (including binders and additives)
  Shell sand
    Oil sand
    CO₂ (sodium silicate)
    Nobake sand
    Other
  Metal melted including recycled sprue
Miscellaneous materials
Annealing room materials
Cleaning room materials
  Grinding wheels and materials
    Steel shot
    Other
  Slag floculant
Fluxes
Scrubber lime
Welding materials
Solid fuels (coke) for cupola melting.

Solid waste material, leaving various foundry processes, was also divided into several categories, depending upon the foundry process from which it was discharged. The categories were:

Refractories
System sand (from molding and including core sand dilution)
Core sand (butts and sweepings not entering the system sand)
Annealing room waste
Cleaning room waste
Slag
Coke ash (collected particulates)
Scrubber discharge
Dust collector discharge
Miscellaneous

Details of these material balances are reported elsewhere.[1-3] This paper makes reference to these details for the purpose of showing how landfill waste can be characterized by the materials balance concept.

Material Balance Data Tables

Tables 1-5 present data on new materials entering the foundry on an annual basis. Tables 6-9 present data on waste materials leaving the foundry. The significance of each table is as follows:

Table 1. Pounds of New Material Purchased Per Year by Category

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	200,200	728,100	52,900	530,000	974,300	32,122	130,334
B. Sand used directly in molding system							
1. New Sand	3,492,000	20,546,000	1,976,200	4,725,800	11,944,000	429,713	1,340,200
2. Clay	1,012,800	3,677,700	95,700	2,160,000	1,847,000	93,100	334,000
3. Carbon	387,200	734,300	24,100	1,584,000	154,200	76,500	
Subtotal:	4,892,000	24,938,000	2,096,000	8,469,800	13,945,200	599,313	1,674,200
C. Sand used as Cores							
1. Shell Sand	558,000	3,976,000	2,226,700	1,800,700	913,800	276,000	877,800
2. Other Core			1,651,000			18,121	71,894
3. Oil Sand	2,243,800	4,076,000		15,200,600	7,430,600	1,973,090	
4. No-Bake				3,540,000			1,131,792
5. CO_2 Sand				2,688,000		2,655,130	167,344
Subtotal:	2,801,800	8,052,000	3,977,700	23,236,300	8,344,400	4,922,341	2,248,830
Total Sand Binder & Additives	7,693,800	32,990,000	5,963,700	31,707,100	22,289,600	5,521,651	3,932,030
D. Metal	27,805,000	63,209,000	6,954,200	122,205,000	36,725,800	3,591,208	16,666,201
E. Miscellaneous	25,800		105,000		35,000	9,440	6,171
F. Annealing Room	220,000						
G. Cleaning Room							
1. Grinding	13,800	129,000	24,200	29,300	88,600	1,000	1,507
2. Steel Shot	49,100	126,000	12,000	216,000	48,800	23,400	93,307
3. Other	5,400		60,000	6,000	1,777,800		
Subtotal	68,300	255,000	96,200	251,300	1,915,200	24,400	93,307
H. Slag Floculant	38,900	1,396,000					
1. Flux		5,658,000		8,544,000			
J. Scrubber Lime		32,500		400,000			
K. Welding					119,400		
L. Coke		8,672,000		27,516,000			
Other	101,800	1,200					
TOTAL	36,153,800	112,941,800	13,172,000	185,153,900	62,059,800	9,178,824	20,812,872

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* Represents total sand purchased.

Table 1 — Pounds of each new material purchased annually (1971-72) are listed by category. Weight in each category and total weight vary considerably from foundry to foundry.

Table 2 — Each category of material is expressed as a percentage of the total from Table 1. This helps to make comparisons of processes in the various foundries. However, metal melted does not go to the landfill but becomes the product sold as castings. Metal should therefore be removed from Table 2 as a landfill contributor to develop Table 3.

Table 3 — Each category of material as a percentage of the total new material purchased excluding metal is listed in this table. This is new material that eventually becomes process waste going to the landfill.

Table 4 — Pounds of each category of new material consumed per ton of metal melted is listed in this table. For each foundry, the data in Table 1 for each category is divided by the metal weight. Heat input to refractory, molding and core sand processes is quantitatively determined by the amount of metal melted. Heat input, as metals melted, causes thermal degradation of core and molding sands during processing. The amount of metal melted is greater than the new metal purchased annually as expressed by foundry yield. For the present purpose, yield may be defined in percentage as pounds of good castings per hundred pounds of metal melted. The weight difference between good castings and metal melted is recycled within the foundry melting process, Fig. 2. However, each time it is recycled, more heat is put into core and molding sand processes. Thermal effects are accounted for in pounds of new material consumed per ton of metal melted as listed in Table 4. This table is especially useful in comparing quantities of purchases with quantities of solid waste to landfill from each process.

Table 5 — Pounds of each category of new material consumed per ton of castings shipped is listed in Table 5. The effect of yield causes the difference between values listed in Table 5 versus those in Table 4. Yield is greatly influenced by design and weight of individual castings as well as the kinds of casting processes. Yield comparisons between foundries are very difficult because of many factors which influence yield.

Table 6 — This is the first table dealing with the waste from the foundries studied. The total annual weight of each category of material leaving the foundry is listed. Table 6 includes a listing of coke and its ash as a weight leaving foundries II and IV. However, the carbon in the coke leaves the foundry mainly as carbon oxide gases and

Table 2. Percentage of New Materials by Category Including Metal Melted

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	0.55	0.65	0.40	0.29	1.52	.34	.62
B. Materials Used Directly in Mold System							
1. New Sand	9.67	18.13	25.87	2.55	18.67	4.68	6.44
2. Clay	2.81	3.26	1.25	1.17	2.89	1.01	1.60
3. Carbon	1.07	.65	0.32	0.85	0.24	.83	
Subtotal:	13.55	22.08	27.44	4.57	21.80	6.52	8.04
C. Sand Used as Cores							
1. Shell Sand	1.55	3.52	16.92	0.97	1.43	3.00	4.22
2. Other Core			.88			.19	.35
3. Oil Sand	6.11	3.61		8.21	11.61	21.50	
4. No-Bake				1.91			5.44
5. CO_2 Sand				1.45		28.93	.80
Subtotal:	7.66	7.13	17.80	12.54	13.04	53.62	10.81
Total Sand, Binder & Additives	21.21	29.21	45.24	17.11	34.84		18.84
D. Metal	76.99	55.92	52.83	66.00	57.41	39.15	80.05
E. Miscellaneous	.07	0.03	.80		0.06	.10	.03
F. Annealing Room	.61						
G. Cleaning Room							
1. Grinding	.04	.12	.18	.02	.14		.01
2. Steel Shot	.14	.11	.09	.12	.08	.25	.44
3. Other	.01		.46		2.78	.02	
Subtotal	.19	.23	.73	.14	3.00	.27	.45
H. Slag Floculant	.11	1.24					
I. Flux		5.01		4.61			
J. Scrubber Lime		0.03		0.22			
K. Welding					.19		
L. Coke		7.68		11.63			
Other	.28						
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3. Percentage of Material Purchased by Category Excluding Metal Melted

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	2.40	1.46	.85	.84	3.84	.57	3.14
B. Sand Used Directly in Molding Systems							
1. New Sand	41.83	41.31	31.78	7.51	47.15	7.69	33.27
2. Clay	12.13	7.39	1.54	3.43	7.29	1.67	8.04
3. Carbon	4.64	1.48	.39	2.52	.61	1.37	
Subtotal:	58.60	50.14	33.71	13.46	55.05	10.73	41.31
C. Sand Used as Cores							
1. Shell Sand	6.68	7.99	35.81		3.61	4.94	20.14
2. Other Core Sand			26.37			. .32	1.73
3. Oil Sand	26.87	8.20		24.16	29.33	35.31	
4. No-Bake				5.62			27.25
5. CO_2 Sand				4.27		47.52	4.03
Subtotal:	33.55	16.19	62.18	34.05	32.94	88.09	53.15
Total Sand, Binders & Additives	92.15	66.33	95.88	50.37	87.99	98.82	94.46
E. Miscellaneous	1.53		1.65		.15	.17	.15
F. Annealing Room	2.64						
G. Cleaning Room							
1. Grinding	0.17	.26	0.39	.05	.35	.02	.04
2. Steel Shot	0.59	.25	0.19	.34	.19	.42	2.21
3. Other	0.06		0.96	.01	7.01		
Subtotal	0.82	.51	1.55	0.40	7.55	.44	2.25
H. Slag Floculant	.46	2.81					
I. Flux		11.38		13.57			
J. Scrubber Lime		.07		0.64			
K. Welding					.47		
L. Coke	———	17.44	———	34.18	———	———	———
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4. Pounds of New Material Consumed Annually Per Ton of Metal Melted (Based on New Purchases)

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	14.40	23.04	15.31	8.67	53.05	15.83	65.16
B. Sand Directly in Molding System							
1. New Sand	251.18	649.51	568.32	77.34	650.44	211.83	671.10
2. Clay	72.85	116.39	27.55	35.35	100.55	45.89	167.00
3. Carbon	27.85	23.20	6.93	25.93	8.43	37.71	
Subtotal	351.88	789.10	602.80	138.62	759.42	295.43	837.10
C. Sand Used as Cores							
1. Shell Sand	40.14	125.80	640.39	29.47	49.76	136.06	438.90
2. Other Core			471.95			8.93	35.95
3. Oil Sand	161.40	128.96		248.90	404.65	972.66	
4. No-Bake				57.94			565.90
5. CO_2 Sand				43.99		1308.88	83.67
Subtotal	201.54	254.76	1112.34	380.30	454.41	2426.53	1124.42
Total Sand, Binder & Additives	553.42	1043.86	1715.14	518.92	1213.83	2721.96	1961.52
D. Metal	2000.00	2000.00	2000.00	2000.00	2000.00	3000.00	2000.00
E. Miscellaneous	9.17	0.04	30.20		1.93	4.65	3.09
F. Annealing Room	15.82						
G. Cleaning Room							
1. Grinding	0.99	4.08	6.96	0.48	4.82		.75
2. Steel Shot	3.53	3.99	3.45	3.54	2.66	11.54	45.90
3. Other	0.39		17.26	.10	96.81	.49	
Subtotal	4.91	8.07	27.67	4.12	104.30	12.03	46.65
H. Slag Floculant	2.80	44.17					
I. Flux		179.03		139.83			
J. Scrubber Lime		1.03		6.55			
K. Welding					6.50		
L. Coke	———	274.39	———	352.13	———	———	———
TOTAL	600.52	1573.63	1788.32	1030.22	1379.61	2754.47	2076.42

Table 5. Pounds of New Material Consumed Annually Per Ton of Metal Shipped (Based on New Purchases)

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	40.24	52.80	30.42	17.96	138.25	41.10	162.90
B. Materials Directly to Molding System							
1. New Sand	701.89	1488.45	1136.64	160.16	1694.84	549.83	1675.25
2. Clay	203.55	266.73	55.10	73.19	261.99	119.13	417.50
3. Carbon	77.78	53.17	13.86	53.67	21.96	97.88	
Subtotal:	983.22	1808.35	1205.60	287.02	1978.79	766.84	2092.75
C. Sand used as cores							
1. Shell Sand	112.16	288.31	1280.78	61.02	129.67	353.15	1097.25
2. Other			943.90			23.18	89.88
3. Oil	451.02	295.57		515.39	1054.39	2524.65	
4. No-Bake				119.96			1414.75
5. CO_2				91.09		3397.26	209.18
Subtotal:	563.18	583.88	2224.68	787.46	1184.06	6298.24	2811.06
Subtotal Sand, Binders & Additives	1546.40	2392.23	3430.28	1074.48	3162.85	7065.08	4903.81
D. Metal	5588.94	4583.52	4000.00	4141.28	5211.33	5191.22	3333.33
E. Miscellaneous	25.65	.09	60.40		5.04	1207	7.73
F. Annealing Room	44.22						
G. Cleaning Room							
1. Grinding	2.77	9.35	13.92	0.99	12.57	1.28	1.83
2. Steel Shot	9.87	9.14	6.90	7.32	6.92	29.94	114.80
3. Other	1.09		34.52	90.20	252.27		
Subtotal	13.73	18.49	55.34	8.51	271.76	31.22	116.63
H. Slag Floculant	20.46	101.23					
I. Flux		410.28		289.54			
J. Scrubber Lime		2.36		13.56			
K. Welding					16.94		
L. Coke		628.84		729.13			
Total	1690.70	3606.32	3576.44	2133.18	3594.84	7149.47	5191.07

Table 6. Estimated Pounds of Material Leaving Foundry by Category Per Year*

Foundry	Malleable I	Ductile Iron II	Copper Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	200,200	728,100	52,900	530,000	974,300	32,122	130,344
B. System Sand							
1. Molding Sand from New Material	1,924,100	23,600,000		20,351,600	16,467,900	69,000	
2. Degraded Shell	195,300	6,623,200		382,000	228,500		
3. Other Degraded						615,000	
4. Degraded CO_2	617,600			570,000		443,000	
5. Degraded Oil	503,000			3,226,700	2,938,800		
6. Degraded No-Bake				751,000			
Subtotal	6,240,000	30,222,200	3,544,500	25,281,600	19,635,200	1,127,000	342,000
C. Core Sand Total							
1. Core Butts	1,315,900	1,168,800	280,000	4,929,900	3,167,200	3,777,000	270,000
2. Core Room Sweeping	250,000	260,000	2,040,300	1,790,400	712,800	50,000	200,000
Subtotal	1,565,900	1,428,800	2,320,300	6,720,300	3,880,000	3,827,000	470,000
Total Sand	7,805,900	31,652,000	5,864,800	32,001,900	23,515,200	4,954,000	
D. Annealing Room Waste	200,000						
E. Cleaning Room Waste							
1. Grinding	13,800		22,400	29,300	88,600	1,000	1,507
2. Steel Shot	49,100		12,000	206,000	48,800	23,400	91,800
3. Other	5,400		60,000	6,000	1,777,800		
Subtotal	68,300	1,205,900	94,400	251,300	1,915,200	24,400	93,308
F. Slag	480,000	5,460,000	**	7,968,000	2,488,000	**	**
G. Coke Ash		8,672,000		21,516,000			
H. Scrubber Discharge				1,032,000			
I. Dust Collector Discharge	100,000		52,000	4,800,000	200,000		
J. Miscellaneous	25,200		65,200		35,500		
TOTAL	8,899,600	47,718,000	6,129,300	68,098,600	29,128,200	5,010,522	1,035,652

* Does not include cast products or gaseous wastes.

** Annual tonnages of dross returned to smelter not reported.

Table 7. Estimated Pounds of Material to Landfill Per Year by Category

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	200,200	728,100	52,900	530,000	974,300	32,122	130,334
B. System Sand							
1. Molding Sand from New Material	1,924,100	23,600,000		20,351,600	16,467,900		
2. Degraded Shell	195,300	6,623,200		382,000	228,500	69,000	
3. Other Degraded							
4. Degraded CO_2	617,600			570,300		615,000	
5. Degraded Oil	503,000			3,226,700	2,938,800	443,000	
6. Degraded No-Bake				751,000			
Subtotal:	6,240,000	30,222,200	3,544,500	25,281,600	19,635,200	1,127,000	342,000
C. Core Sand Total							
1. Core Butts	1,315,900	1,168,800	280,000	4,929,900	3,167,299	3,777,000	270,000
1. Core Room Sweepings	250,000	260,000	2,040,300	1,790,400	712,800	50,000	200,000
Subtotal:	1,565,900	1,428,800	2,320,300	6,720,300	3,890,000	3,827,000	470,000
Total Sand	7,805,900	31,652,000	5,864,800	32,001,900	23,513,200	4,954,000	
D. Annealing Room Waste	220,000						
E. Cleaning Room Waste							
1. Grinding	13,800		22,400	29,300	88,600	1,000	1,507
2. Steel Shot	49,100		12,000	216,000	48,800	23,400	91,800
3. Other	5,400		60,000	6,000	1,777,000		
Subtotal:	68,300	1,205,900	94,400	251,300	1,915,200	24,400	93,307
F. Slag	480,000	5,460,000		7,968,000	2,488,000		
G. Coke Ash		882,800		2,190,000			
H. Scrubber Discharge				1,032,000			
I. Dust Collector	100,000		52,000	4,800,000	200,000		
J. Miscellaneous	25,200		65,200		35,500		6,171
TOTAL	8,899,600	39,928,800	6,129,300	48,773,200	29,128,200	5,010,522	1,041,812

Table 8. Estimated Percentage of Materials Leaving Foundry Per Year by Category

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	2.25	1.53	0.86	0.78	3.34	.65	12.51
B. System Sand							
1. Molding Sand from New Materials	55.34	49.45	57.83	29.88	50.54	1.38	
2. Degraded Shell	2.19			0.56	6.78	1.12	
3. Other Degraded Core Sand						1.20	
4. Degraded Oil	5.65	13.89		4.74	10.09	12.27	
5. Degraded CO_2	6.94			0.84		8.84	
6. Degraded No-Bake				1.10			
Subtotal	70.12	63.34	57.83	37.12	67.41	22.49	32.83
C. Core Sand Total							
1. Core Butts	14.79	2.45	33.29	7.24	10.87	5.39	25.92
2. Core Room Sweepings	2.81	0.55	4.57	2.63	2.48	.81	19.20
Subtotal:	17.60	3.00	37.86	9.87	13.35	75.38	45.12
Total Sand	87.72	66.34	95.39	46.99	80.76	98.87	77.95
D. Annealing Room Waste	2.47						
E. Cleaning Room Waste							
1. Grinding	0.16		0.36	0.04	0.30	.02	.14
2. Steel Shot	0.55		0.20	0.32	0.16	.46	8.81
3. Other	0.06		0.98	0.01	6.10		
Subtotal	.77	2.53	1.54	.37	6.56	.48	8.96
F. Slag	5.39	11.44	*	11.70	8.54	*	*
G. Coke		18.16		31.60			
H. Scrubber Discharge				1.52			
I. Dust Collector Discharge	1.12		.85	7.05	0.69		
J. Miscellaneous	0.28		1.06		0.		.58
TOTAL	100.0	100.00	100.00	100.00	100.00	100.00	100.00

* Dross returned to smelter for reclaiming not included.

Table 9. Estimated Percentage of Material to Landfill Per Year by Category

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	2.25%	1.82%	0.86%	1.09%	3.54%	.65%	12.51%
B. System Sand							
1. Molding Sand Materials	55.34	59.11	57.83	41.72	50.54		
2. Degraded Shell	2.19	16.59		0.78	6.78	1.38	
3. Other Degraded Core							
4. Degraded Oil	5.65			6.62	10.09	12.27	
5. Degraded CO_2	6.94			1.17		8.84	
6. Degraded No-Bake				1.54			
Subtotal:	70.12	75.70	57.83	51.83	67.41	22.49	32.83
C. Core Sand Total							
1. Core Butts	14.79	0.65	33.29	10.11	10.87	75.39	25.92
2. Core Room Sweepings	2.81	2.93	4.57	3.67	2.48	.99	19.20
Subtotal:	17.60	3.58	37.86	13.78	13.35	76.38	45.12
Total Sand	87.72	79.28	95.69	65.61	80.76	98.87	77.95
D. Annealing Room Waste	2.47						
E. Cleaning Room Waste							
1. Grinding	0.16		0.36	.06	0.30	.02	.14
2. Steel Shot	0.55		0.20	.44	0.16	.46	8.81
3. Other	0.06		0.98	.01	6.10		
Subtotal:	0.77	3.02	1.54	.51	6.56	.48	8.96
F. Slag	5.39	13.67		16.34	8.54		
G. Coke Ash		2.21		4.49			
H. Scrubber Discharge				2.12			
I. Dust Collector Discharge	1.12		0.85	9.84	0.69		
J. Miscellaneous	0.28		1.06		0.12		.58
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Sand Percentage Excluding Slag, Coke Ash and Refractories	95.0	96.3	96.1	83.0	91.9	99.5	89.1

hence does not go to the landfill. The coke ash and dirt either becomes slag or particulate solid waste, both of these go to the landfill. The material balance of solids entering and leaving the foundry should account for those entering as solids and leaving as gases. This is of principal importance in the case of coke used in cupola melting, (foundries II & IV).

Table 7 — Pounds of waste going to the landfill annually in each category is listed in Table 7. Comparison of Tables 6 and 7 shows how total solid waste leaving the foundry is reduced by conversion of coke carbon to gases.

Table 8 — Each category of waste material as a percentage of the total waste leaving the foundry is given in Table 8. This is obtained by dividing each item in Table 6 by the total weight of waste for each foundry. Coke for cupola melting (foundries II & IV) is included as related in connection with Table 6.

Table 9 — This table, which is similar to Table 8, shows percentages of solid waste actually sent to landfill. An adjustment is shown to exclude losses resulting from processes, such as conversion of coke to coke ash and so forth.

Table 10 — Pounds of solid waste to the landfill in each category per ton of metal melted is listed in this table. The values are obtained by dividing weight of waste in each category in Table 7 by weight of metal from Table 1. Pounds of waste per ton is the material subject to heat input and discussed under Table 4. Table 10 indicates the amount of waste which a foundry might estimate it would produce in relation to its annual tonnage melted unless it changed its processes or the kind of castings produced.

Table 11 — The pounds of each category of solid waste to the landfill per ton of castings shipped is listed in Table 11. This table differs from Table 10 because of yield factors discussed in Table 5.

Tables of data are used in the following discussions of foundry processes which generate the solid waste that goes to the landfill.

Core Processing

Materials flow in processing is shown in Fig. 1. Consider first the core sand processing loop. Cores are solid forms made of sand mixed with about 0.75-5% of a binder that hardens when the aggregate is cured. Organic binders are initially liquid or solid resinous carbon compounds. Curing can be done by baking at about 400-600F (204-316C) or by using catalysts at near ambient temperatures. Polymerization and oxidation are the principal curing reactions. Specific core and binder formulations and processing have been described elsewhere.[1-4] Chemical reactions involved are not discussed here, as the principle objective is to relate the course of processing to the waste produced.

Table 10. Estimated Pounds of Material to Landfill Per Ton of Metal Melted

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	14.40	23.05	15.21	8.67	53.05	15.83	15.48
B. System Sand							
1. Molding Sand - New Material	354.19	537.16		333.08	896.81		
2. Degraded Shell	14.05	209.57		6.25	12.44	34.01	
3. Other Degraded Core Sand							
4. Degraded Oil	36.18			52.81	160.04	218.38	
5. Degraded CO2	44.42			9.33		303.17	
6. Degraded No-Bake				12.29			
Subtotal	448.84	746.73	1019.38	413.76	1069.29	555.56	40.62
C. Core Sand Total							
1. Core Butts	94.65	36.98	586.78	80.68	172.48	1861.92	32.07
2. Core Room Sweepings	17.98	8.23	80.53	29.30	38.82	24.65	23.76
Subtotal:	112.63	45.21	667.31	109.98	211.30	1886.57	55.83
Total Sand	561.47	791.94	1686.69	523.74	1280.59	2442.13	96.45
D. Annealing Room Waste	15.82						
E. Cleaning Room Waste							
1. Grinding	0.99		6.44	0.48	4.82	.49	.18
2. Steel Shot	3.53		3.45	3.54	2.66	11.54	10.90
3. Other	0.39		17.26	0.10	96.81		
Subtotal	4.91	38.16	27.15	4.12	104.29	12.03	11.08
F. Slag	34.53	172.76		130.50	135.49		
G. Coke Ash		27.93		35.85			
H. Scrubber Discharge				16.89			
I. Dust Collector Discharge	7.19		14.95	78.56	10.89		
J. Miscellaneous	1.81		18.75		1.93	4.67	.73
TOTAL	640.13	1053.84	1762.75	798.33	1586.25	2474.66	123.74

Table 11. Estimated Pounds of Material to Landfill Per Ton of Metal Shipped

Foundry	Malleable I	Ductile Iron II	Copper-Base III	Gray & Ductile Iron IV	Steel V	Aluminum VI	Copper-Base VII
A. Refractories	40.25	52.80	30.43	17.96	138.25	41.10	38.70
B. System Sand							
1. Molding Sand - New Materiel	989.76	1711.32	2038.77	689.68	2336.77		
2. Degraded Shell	39.26			12.94	32.42	88.29	
3. Other Degraded Core Sand							
4. Degraded Oil	101.11	480.27		109.34	417.01	566.83	
5. Degraded CO2	124.14			19.33		786.92	
6. Degraded No-Bake				25.45			
Subtotal	1254.27	2191.59	2038.77	856.74	2786.20	1442.04	101.55
C. Core Sand Total							
1. Core Butts	264.50	84.75	1173.56	167.06	449.42	4832.83	80.18
2. Core Room Sweepings	50.25	18.85	161.05	60.67	101.15	63.98	59.40
Subtotal:	314.75	103.60	1334.61	227.73	550.57	4896.81	139.58
Total Sand	1569.08	2295.19	3373.38	1084.48	3336.77	6338.85	241.18
D. Annealing Room Waste	44.22						
E. Cleaning Room Waste							
1. Grinding	2.77		12.88	0.99	12.57	1.28	.45
2. Steel Shot	9.87		6.90	7.32	6.92	29.94	27.25
3. Other	1.09		34.51	0.20	252.27		
Subtotal	13.73	87.44	54.29	8.51	271.76	31.22	27.70
F. Slag	96.48	395.92		270.02	353.04		
G. Coke Ash		64.02		74.22			
H. Scrubber Discharge				34.97			
I. Dust Collector Discharge	20.10		29.21	162.67	28.38		
J. Miscellaneous	5.06		37.50		5.03	12.07	1.83
TOTAL	1788.86	2895.36	3524.81	1652.83	4133.23	6423.24	309.35

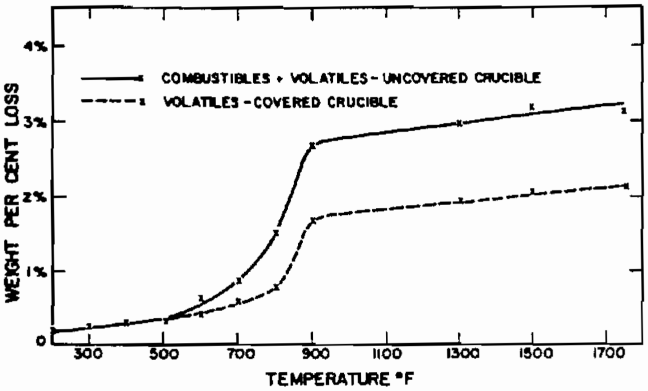


Fig. 3. Volatiles, combustibles vs temperatures for 4% shell sand.

Curing, followed by thermal degradation by heat from molten metal, are the main events in the processing cycle that influences solid waste production. When heated, resinous binders soften, begin to volatilize, char and oxidize as temperature and time increase. A volatilization curve for a 4% phenol formaldehyde shell core sand mixture illustrates this behavior, Fig. 3. Volatilization begins only slightly over ambient temperature, Fig. 3. Part of the binder is driven off during initial resin-coating of the shell sand, as well as during curing when the core is made. However, most of the binder is driven off in the 600-900F (316-482C) temperature range as resin decomposes, mainly to CO_2, CO, H_2 and water vapor. Carbon char remains, with some additional loss to 1700F (927C). In an open crucible, oxidation of the resin and char leads to a greater total volatilization of binder, Fig. 3. Oxidizing conditions burn off carbon as degraded core sand proceeds through the shakeout operations.

The volatilization curve of Fig. 3 can also be expressed as a relationship of the percentage of total binder volatilized, oxidized and charred in an open crucible after 30 min at temperatures as shown in Fig. 4. For example, 3% weight loss in a 4% binder-sand mixture means 75% of the total binder is lost. This relationship has been plotted for all resin-type core binders tested, Fig. 4. Most of the binder is lost once a temperature of about 1000F (538C) is exceeded. Below 900F (482C) degradation varies somewhat with binder type. All carbonaceous resins and sand additives studied thus far follow the degradation curves shown in Fig. 4.

Core sands can be grouped in four process stages in relation to the thermal effects revealed in Fig. 4.

1) Freshly mixed, uncured sand (sweepings).
2) Cured sand in cores.
3) Thermally degraded sand heated over 1000F (538C). This is shaken out from castings.
4) Core butts. Sand not exposed to mold temperatures over about 600F (316C); not sufficiently thermally degraded to decompose the binder so the core form is retained.

The total amount of new sand purchased for core sand use is listed in Table 1, for each of the major binders. Table 2 lists the amount as a percentage of total new purchases. Sand is mixed with binders in the foundry or in the case of shell core sand, is sometimes purchased with binder already present as a sand grain coating.

Sand dropped on the floor while handling and making cores is swept up and transferred to landfill waste as sweepings. The percentage of sweepings in the total waste is listed in Table 9. This sand has not been exposed to the curing process and therefore contains the percentage of binders in the initial mixture.

Cores exposed to hot metal lose their strength due to thermal degradation. When degradation is complete (over 900-1000F (482-538C)), the sand no longer has strength; it falls away from castings in shakeout and becomes a part of the molding sand. In molding sand, it is exposed to additional heat since molding sand may complete twenty or more cycles of use before it goes to the landfill. Degraded core sand in molding sand thus will be substantially free of its binder by the time it reaches landfill as part of the system sand. The only undegraded core sands reaching landfill are sweepings and core butts. Core butts are remnants of cores not heated to a high enough temperature by metal to cause degradation. After shakeout, these core chunks are screened from molding sand in pieces usually larger than 1/4 x 1/4 in. and sent to landfill. Unused defective cores and broken cores are included in core butt process waste. Core butts, as a weight percentage of the total waste are shown in Table 9.

The pounds of core sand purchased per ton of metal melted, Table 4 reveals the extent of core processing done in a foundry. Foundries III VI and VII, copper and aluminum alloy foundries, have very high core sand use. Foundry III used its sand only once. Foundry VI had the highest weight ratio of core use. Ferrous foundries show new core sand purchases of 200-460 lb/ton of metal melted, revealing similar levels of coring.

Pounds of core sand to landfill Table 10 is also reflected in new sand purchases. Ferrous foundries discarded 45-212 lb/ton melted. Foundries III and VI, producing copper and aluminum castings respectively, discarded much higher weight ratios. However, foundry VII, another copper alloy producer, shows a large drop in weight of sand to landfill because most of its sand is sent to a smelter for recovery of entrapped metal.

Leachable Core Sand Waste

Core binders and additives are the only potentially leachable constituents of core sands.[12] The thermally degraded binder and additives contribute very little to leachate. Only sweepings and core butts may contribute significantly. Assuming a binder level of 2.5%, the percent of core binder in the total waste from a foundry can be estimated from the percentage of core butts and sweepings in the total, Table 10. This percentage varies from a low of about 0.09% from foundry II to a high of about 2.3% from foundry VI. Differences are due to the percentage of cores used and the kind of metal cast.

Molding Sand

System molding sand consists of sand, clay binder and additives, plus low levels of organic residues from undecomposed core binders. The clay binder is usually a natural western or southern bentonite, or sometimes fireclay, in amounts varying from 5-15% by weight. Return sand added to the muller consists partially of freshly degraded core sand from shakeout and degraded core sand from previous molding cycles. Systematic additions of new sand and clay are added during mulling as required. That part of the total sand purchased for initial use as core sand is shown in Tables 1 and 2. This table also shows the portion of total sand purchased which is used as new molding sand, together with clay and additives. Spent system sand, plus core sweepings and butts, eventually end up as the total sand contribution to solid waste landfill, Table 7.

With each reuse cycle, the system sand containing degraded core sand, added new sand, clay binder and additives undergoes some thermal degradation from heat absorbed from metal poured into the molds. Additives in sand mixes are carbonaceous materials such as pulverized coal, cellulose, starch or cereal flour total 1.0-7.0%. These respond to thermal degradation in the same manner as core sand binders, Fig. 3 and 4. Details of this behavior are in references 1-7 and 14. Clay binder is inorganic, not carbonaceous. Clay may lose water of crystallization, may undergo fusion and crystal structure changes as temperatures of 1000-1700F (538-927C) are exceeded. This occurs, however, to only about 5% of total clay in the sand with each cycle.[5]

System sand is gradually replaced within 20 or more cycles by dilution from degraded core sand from shakeout and from sand and binder additions to the sand mixer during recycling. Displaced sand goes to landfill as system sand, Fig. 2. Waste system sand, as a percent of the total, varies from 65-99% of total landfill waste, Table 9.

Leachable System Sand Waste

Undegraded bentonite clay is the principal active ingredient of system sand waste in landfills. It is indicated that thermally degraded carbonaceous additives in waste system sand have little leachate-forming effect.[1] Further, the clay is essentially a nonleachable constituent. However, it has two important properties which can be useful in landfill leachate control. First it has a high absorbing capacity for many water-soluble organic and inorganic substances. This can prevent or limit soluble constituents of foundry waste from leaching out of the landfill. Second, bentonite clays swell appreciably when exposed to moisture. This can limit or control the flow of water through the waste. Because of these properties, it was considered important to investigate effects of clay on leachate formation in landfills. The percentage of clay in the total waste from a foundry can be estimated from the percentage of system sand in the total waste, Table 9, assuming 6.0% clay in system sand. On this basis, clay percentage ranged from 1.35% (foundry VI) to a high of 4.5% (foundry II). Effects of clay amount and type on leachate formation are reported in subsequent sections.

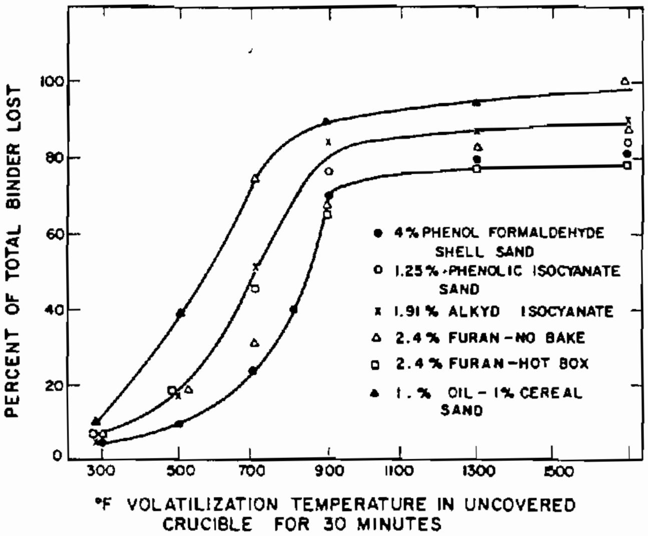


Fig. 4. Volatilization temperature (°F) in uncovered crucible for 30 min.

Melting and Pouring, Ferrous Foundries

Refractories, slags and dust collector particulates are the principal wastes from the melting and pouring process cycle. Oxides form when metals are melted in preparation for pouring into molds. The oxides may occur as slag or dross which is usually treated with flux for convenience in separating it from the metal. In cupola melting a major source of slag is the 6-10% of ash in coke used as fuel. This is fluxed with limestone, dolomite, fluorspar or other fluxing materials and leaves the cupola as a molten slag that solidifies to a glassy solid. Metal particles may be entrained in the slag. Slags and drosses may also result from copper and aluminum alloy melting. However, these are normally reclaimed, as stated earlier, and not sent to landfill. The percentages of melting material that enter the solid waste aggregate as refractories, slag, ash particulates and dust collector material vary from 6.8 to 32.8% in the ferrous foundries, I, II, IV and V, in Table 3. However, the two foundries with cupolas have 15.9-32.8% of this material while the others have less than 10%. The leachate-forming behavior of this material is low.[1]

Cleaning, Heat Treating and Inspection

Cleaning refers to the operations of removing risers and gating, excess metal, repairs if necessary, surface conditions and preparing the castings for shipment. Metal removed from the casting returns to the melting cycle. The principal wastes generated are grinding wheel and metal dust, abrasive shot dust, welding refuse and dust collector particulates. Table 9 shows this to be less than 8.96% of total waste and mainly less than 6.56%. There is also a small amount of waste from heat-treating operations. All this waste is comprised mainly of metallic oxides and metallics and may have little leachate potential.[1]

Finally, inspection operations determine whether any of the castings are defective. Those which are unsatisfactory are recycled to the melting process and will not appear as waste listed in Table 9.

Solid Waste Quantity and Melt Tonnage

The range of percentages of each type of waste to be expected in total solid wastes from green sand foundries has been shown by these studies. The quantity of waste from a foundry can be expressed in relation to the tonnage of metal melted, Table 10. The quantity of waste varies from 123 to 1763 lb/ton of metal melted on an annual basis. The range is readily related to differences in the melting process used, type of castings made, types of core and molding processes used, the casting alloy and other foundry processing characteristics.

Ferrous Foundries

The total solid waste per ton of metal melted varies from 640 to 1586 lb, Table 10. The high value in the range is from steel foundry V. It is mainly a result of using about 400 lb/ton more new molding sand materials for steel castings than for cast irons. Higher processing temperatures with steel usually require more new sand and refractories. The low value in the range is from foundry I which uses electric induction melting. This generates less melting waste than cast iron foundries II and IV using coke-fired cupolas. The latter foundries generate about 800-1000 lb of waste per ton melted. Thus the range of 640-1586 lb of solid waste per ton of metal melted is conclusively related to the foundry processes and products.

Copper and Aluminum Foundries

While operations at nonferrous foundries are similar to ferrous foundries with respect to types of processes and materials used, there were certain differences. Since the metals cast are nonmagnetic, separation of metallic dripping and shot from the sand, dross and slag is more difficult. Because of contained metal value, some of these wastes can be sent to a smelter for reclaiming and recycling of the metal. Aluminum foundry VI in Table 10 sends dross, slag and some defective castings to a smelter. Copper alloy foundry VI in Table 10 sends a large amount of system sand to a smelter to recover metal. These practices obviously reduce the pounds of material going to the landfill per ton of metal melted in foundries VI and VII. In contrast, copper alloy foundry III in Table 10 is unique among the seven studies since it uses its core and molding sand only once. This accounts for the high value of 1763 lb of waste per ton metal melted in foundry III compared to the 128 lb/ton in foundry VII.

As expected, aluminum foundry VI has a lower rate of generated solid waste, 274.66 lb/ton melted. If one considers the difference in metal density of aluminum as compared to that of iron, then the value becomes (274.66 x 7.9) ÷ 2.7 or 803.63 lb/ton melted. This is seen to fall into the middle of the range for the ferrous alloys. Again it is evident that the nonferrous alloys show excellent correlation of foundry processes and solid waste generation rate in pounds of solid waste per ton of metal melted.

Accuracy

A balance of process materials going into and coming out of a foundry should fulfill valid accuracy criteria. In this research the balance of outgoing solid waste was found to occur within ± 5% of the ingoing new materials.[2]

Summary

A materials balance has related new solid materials purchased that enter foundry processing with solid process waste going from foundry to landfill. Spent sand is the major waste material amounting to 65-99% of the total solid waste going to landfill. Melting processes and cleaning room waste account for most of the remaining waste. The proportions of each category of waste sent to the landfill, i.e., landfill composition by category, are given, Table 9, for seven foundries of diverse alloys and processing. The quantity of total waste produced was found to be 650-1753 lb/ton of metal melted in four ferrous foundries and 124-1763 lb/ton of metal melted in three nonferrous foundries. The wide range is due to processing and disposal differences in the foundries, as well as differences in alloy densities. Consideration of the relationship between foundry products, processing techniques and waste disposal permits a valid balance of ingoing and outgoing materials to be achieved. Those ingredients of the landfill waste most likely to influence the quality and quantity of leachate have been categorized and percentages of leachate present have been related to foundry type and processing methods.

2

Preliminary Studies on Leachates from Foundry Process Solid Wastes

Environmental standards at federal and state levels have been developed for control of waste discharges to air, water and land. These standards have meant a new look at all kinds of waste materials, including those from industrial sources. Possible effects on surface and groundwater are the primary concerns. The foundry industry as well as pollution control agencies are interested in determining the effects of these disposal practices on the environment.

Based on this background, the American Foundrymen's Society has sponsored a research project at the University of Wisconsin to determine those effects. The primary objective of the research was to determine the quantitative and qualitative pollution characteristics of leachate from selected foundry process solid wastes. Leachate is a polluted liquid formed by percolation or movement of water through a waste material. During contact with the waste this water picks up certain dissolved and suspended matter. The liquid containing this matter is referred to as leachate.

Leachate studies have been conducted, based on materials and waste balance studies, to examine the characteristics of any leachates that can be expected from foundry waste materials. Leachate studies have consisted of two phases. Phase A presents preliminary information about maximum amounts of contaminants which can be produced by intimate contact of selected foundry wastes with water (reported in this chapter). Phase B compares those maximum amounts and related information obtained in phase A studies with amounts released under simulated landfill conditions. This information is contained in chapters 3 and 4.

1) To develop a standardized laboratory testing procedure for the entire series of tests for use in determining leachability of matter from various sands. Comparison of results from the laboratory testing procedure with results from simulated landfill situations (examined in phase B) will define relationships to be used in estimating in-field leachate results.
2) Use of this procedure to examine leachability of matter in various sands to determine maximum release under intimate contact with water.
3) To compare release among various sands and to determine those with the greatest leaching potential.

Foundry Solid Waste Handling and Disposal Practices

Land disposal is the only true disposal activity practiced by the foundry industry for waste sand materials. Some foundries may have various systems installed for sand reclamation but even these result in residues that are disposed of on land. Waste sand is usually in the form of a mixed waste load made up of sands and other wastes generated by several different sources within the plant. These wastes originate from corerooms, shakeout areas, dust collectors, system sand excess and other sources. The sands and other waste materials have been subjected to a variety of operations, processes and temperature ranges within the foundry.

Waste Handling and Disposal Practices

Although sluicing or hydraulic conveyance of wastes is occasionally practiced, the wastes are usually dry-handled and trucked to a land disposal site.

Many different types of sites are used for disposal of foundry solid wastes. Municipal or private sanitary landfills, which accept other varieties of solid waste including garbage and trash, accept foundry solid wastes as ground cover. Waste foundry materials are more often discarded in privately owned sites used exclusively for those wastes, or in sites adjacent to and owned by individual foundries.

Physical characteristics of these sites vary widely. While some sites are large in size and capacity, they are often small with short-term capacity. It is not uncommon for private landowners to request loads of foundry sand waste as fill for small low areas to improve the land's development potential.

The physical setting of disposal sites varies from high-and-dry types to lowlands and shorelines. Sites located in topographically high areas are also typically considered to be hydrogeologic recharge areas.

Rainfall entering a recharge area travels downward to join groundwater supplies by further downward and sometimes lateral movement. On the other hand, sites located in lowlands are considered to be in discharge areas. The gradients of water movement in discharge areas are usually upward and groundwater levels are generally a short distance below ground surface. It has been a fairly common practice in disposal of foundry solid wastes, as well as in disposal of other wastes, to use wetland or discharge type areas. In areas such as these, waste material is often water-saturated from the presence of surface water or shallow groundwater. In the past, selection of these sites often has been similar to the selection of disposal sites for other industrial and municipal wastes. Land selection decisions were made based on land availability within reasonable haul distance of the foundry and at the right price.

Various onsite operating procedures are used to dispose of waste materials. At some sites, waste sand and other materials are randomly dumped and graded, either periodically or upon completion (filling) of the site, to provide a fairly smooth surface. In some cases foundry wastes have been combined with other industrial and municipal wastes in a sanitary landfill. In these instances, foundry wastes are often used as supplementary daily cover material over other wastes. In other sites, foundry waste is graded upon deposition and covered with earth and topsoil. After revegetation, land is provided for other uses.

While other disposal practices certainly exist for handling foundry solid wastes, the practices and site features discussed here are some of the most common. It is felt that the type of site and operating procedure used can have significant importance on the effect of any leachate on ground and surface water. These physical relationships are further examined in phase B of the leachate studies.

Development of a Standardized Laboratory Testing Procedure

The objective of this portion of the research project was to develop a standardized procedure for determining maximum leachability, or matter release, from foundry sand waste materials. The procedure was designed to maximize release values as a logical first step in predicting actual release under natural landfill disposal conditions. After conducting additional tests relating directly to in-field disposal conditions, relationships and correlations can be drawn between results from the laboratory procedure and results to be expected under actual disposal conditions.

Testing procedures involve determinations of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) requirements of foundry sand wastes. COD is a test used to measure pollutional strengths of domestic and industrial wastes. This test measures the organic content of a waste in terms of quantity of oxygen required for oxidation of the waste to carbon dioxide and water. During a determination of COD, organic matter is converted to carbon dioxide and water regardless of the assimilability of the substance. Biochemical oxygen demand (BOD) measures the amount of oxygen required by bacteria while destabilizing decomposable organic matter under aerobic (action in the presence of oxygen) conditions. BOD tests determine pollutional strengths of domestic and industrial wastes in terms of the oxygen they will require if discharged into natural water courses in which aerobic conditions exist.

COD values are greater than BOD values and can be much greater when significant amounts of biologically resistant organic matter are present. In conjunction with the BOD test, COD tests indicate any toxic conditions and the presence of biologically resistent organic substances. Both tests are used in this study.

Several variations of testing methods are used for extracting or leaching matter from solid materials. While development or standardization work for these test methods is not well described in the literature, general procedures are outlined in some cases. It was verified through literature review that the test method selected depends primarily on the objectives of experimentation. These were found to range from determining maximum leachability in a short period of time to simulating actual landfill leaching conditions, or to fulfilling other objectives.

Test methods for determining leaching characteristics have been applied to a variety of waste materials. However, literature review indicated little detailed documentation for tests conducted on foundry sand wastes.

One large chemical company[9] has used a two-step technique of combining 50 g of sand with 100 ml of water, mixing, allowing to settle and sit overnight and then filtering the water plus an additional 100 ml of rinse water. The total 200 ml are available for analysis. The second step is similar to the first except that quantities of sand, water and rinse water are more than doubled. This testing concluded that curing of binders results in substantial reduction of leachable constituents. In general, shakeout sands (those subject to metal pouring temperatures) were shown to contain negligible or very small amounts of leachable components.

Another company[10] has used a procedure whereby 500 g of sand is combined with 2000 ml of deionized distilled water and agitated for 48 hr before the solution is extracted and analyzed.

Some foundry sand leaching studies conducted in Germany[11] used multistep passage of water through a plexiglass column filled with foundry sand. Columns were layered on top and bottom with silica to ensure uniform distribution of eluting waters over the column cross-sections. A uniform flow of 5 liters of water per 24 hr was established for a one-to-five-stage elution process. Eluted water and eluted matter were examined.

One test facility[12] worked to develop test methods for determining degree of leaching of landfilled wastes and, in particular, their proprietary solids. A test procedure was developed, based on five criteria set by the parent company and generally stated here:

1) The rate of leaching must be determined by the method (i.e. steady-state method).
2) Natural leaching conditions should be simulated.
3) An understanding of the difference between normal effluent standards and leachate standards is important.
4) Characteristics of each waste sample vary according to additives used in producing the solid.
5) Leaching characteristics depend on:
    Chemical reactions of solids with diluents
    Permeability of solids to the diluent.

Based on these criteria, the parent company developed a standard leachate test for use in their facilities. The test uses column studies in which distilled water is passed through a compacted column of material. Leachate is collected in specified portions and analyzed.

Experimentation by Benedict, McKeown and Hart[13] was designed to establish methods for estimating potential contribution of leachate material from wood bark residues under static leaching conditions. The studies were designed to define effect of contact time on concentration buildup of various types of leachable matter.

Known quantities of wet bark were placed in columns and combined with measured quantities of distilled water in some columns and saline water in others. Bark was combined with water in a 1:1 mix (wet weight basis). The effect of contact time on bark leaching under static conditions was evaluated by leaving the columns undisturbed, except for periodic withdrawal of contact water for analysis, for periods up to 85 days.

Data on COD and BOD_5 (biochemical oxygen demand after 5 days) was fit to a static leaching equation to predict the limiting concentration of extractive under static leaching conditions.

In other work, Benedict, McKeown and Hart[14] conducted dynamic leaching studies to define interdependence of time of contact, contact water volume, bark quantity and field-storage age on BOD_5, COD and color leaching from wood barks and to study washout of BOD_5, COD and color by repetitive contact of bark with fresh water. Distilled water was used to simulate fresh water conditions. Known quantities of wet bark were placed in columns and combined with contact water. Bark leaching under flowthrough conditions was studied by passing contact water upward through the bark-filled columns at a known flow rate. Flow rate was adjusted to provide specified contact times.

Asano, Towlerton and Sanks[15] conducted research to evaluate the rate at which, and extent to which, selected pollution constituents leach or diffuse from wood chips transported in hydraulic pipelines. Simulated hydraulic pipelines were used to contain and agitate distilled water containing various concentrations of wood chips. Time of immersion and agitation covered a range of 10-40 hr. Samples were withdrawn and analyzed at appropriate intervals throughout the agitation period. One conclusion reached in this work was that the most rapid leaching of substances from the wood chips occurs at time of immersion. During the first 2 hr of agitation, approximately two-thirds of the total amount was released into the water. After 4 hr, the rate of leaching was slow except for color.

Several studies have been conducted to determine concentrations and quantities of solutes which can be leached from combustion byproducts, fly ash in particular. These studies are summarized in a report by O'Conner, Virshbo, Cain and O'Brien.[16]

In one Wisconsin study, several samples of combustion byproducts were obtained from a landfill. A dried 50-g portion of each sample was placed in a beaker and then contacted with 500 ml of demineralized water at 72F (22C) and the mixture stirred for 30 min. After decanting the liquid with its extracted solutes, solid residue was again contacted with 500 ml of demineralized water, this time at 212F (100C) and the mixture stirred again for 30 min. An interpretation of results by O'Conner, Virshbo, Cain and O'Brien[16] indicated this double extraction of solutes from fly ash samples was a simulated, accelerated test for leachable materials. Comparable extraction under natural conditions would take a considerable length of time.

A study in Illinois made use of columns loaded with ash and slag samples which were subjected to repeated elutions with demineralized water in an effort to determine approximately how much solute could be leached. Approximately 1-kg quantities of wastes were loaded into columns and extracted successively with 1-liter portions of demineralized water. It was apparent that first elutes were very high in dissolved matter. The authors indicated these high levels may not be representative of those which would be found in a leachate from an actual combustion byproducts landfill.

Procedure Development Through Experimentation

The basic testing technique examined in this study was the shake-flask method. This method measures the amount of matter which can be removed from foundry sand materials by direct solubility or desorption and indicates which materials may be of particular concern in disposal. The shake-flask method does not measure any filtering effects of sands in removing matter from leachates nor does it measure any effect of biological activity which may be present in the sands under actual landfill disposal conditions. However, it is a relatively rapid and uncomplicated method that can be used to obtain maximum release of matter under conditions of continuous sand-water contact. Shaking provides thorough mixing of flask contents. Much testing has been conducted to develop the standardized shake-flask procedure described here. Standard wet chemical methods[17] were used to analyze for parameters such as COD, BOD, solids and pH. Alkalinity analysis was done by titration to the methyl orange end point and nitrated nitrite by the Keeney Micro Kjeldahl method.[18]

The sand material used during test procedure development was a shell sand consisting of 96% silica with 4% phenol-formaldehyde resin. This material was cured by baking thin slabs (1/4-1/2-in.-thick) at 400F (204C) and at 500F (260C). Thin slabs were used to ensure uniform curing and were heated between two 5 x 14-in. plain carbon steel sheets to prevent excessive oxidation of the sand resin. The cured shell sand was crushed in a ball mill for 1 hr. This material was used through six phases of testing in order to standardize the shake-flask method for this application.

A detailed presentation of the testing program appears in chapter 3. Several variables affecting test results were specifically examined in the testing program with these conclusions:

Method of sand sample selection and preparation — During the early tests, it was found necessary to use a soil testing technique of sample mixing and splitting to obtain a sample representative of the source material.

Quantity of sand sample — It was found after several tests that a 100-g sample of sand would provide a small enough amount of material to be workable and yet provide a large enough quantity to be representative of the source material and to yield repeatable results.

Volume of sample water — Distilled water was used as sample medium, to simulate rainwater, because testing objectives were to determine matter release in water and, in future testing, to relate results to natural environmental conditions. Four hundred ml of sample water was found to be workable and to provide enough liquid for all necessary analytical tests.

The ratio of 100 g of sand to 400 ml of water was chosen through a comparison of release results from samples with several different sand-water ratios. Analysis of results from earlier phases of test development showed that sand-water ratios of less than 50 g of sand in 400 ml of water gave unpredictable and nonreproducible results. On the other hand, ratios greater than 50 g of sand in 400 ml of water gave reproducible results. A curve verifying this finding has been reproduced from chapter 3 and is presented in Fig. 5.

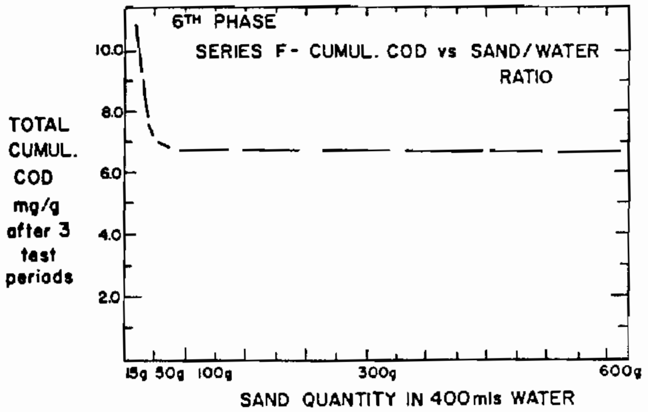


Fig. 5. Total cumulative COD vs sand/water ratio.

Particle size of sand sample — Early tests showed less release of matter from pellets made of many bonded sand particles than from individual sand particles. However, to provide a homogenous sample and to obtain maximum matter release, sand consisting primarily of individual particles was used in the standardized procedure. Hence, for most sands tested, it was necessary to pulverize or mill them because of bonds formed by heating and by various chemical bonding reactions.

Method and extent of shaking — Reciprocating shakers used with wide-mouthed 2-qt mason jars were found to provide adequate mixing action. Eberbach shakers were used, operating at a speed of 180 complete vibrations per minute. Jars were vibrated through a distance of approximately 1-1/2 in. in a horizontal plane. To prevent excessive stress on sand particles, shaking was done only twice per day for approximately 15-30 sec each. Continuous shaking was not found to be desirable, since the objective of shaking is only to provide complete sand-water mixing for release purposes without abrading sand particles.

Sample retrieval — To obtain maximum matter release from sand samples on a cumulative basis, it was found necessary to first wash solid residue remaining in the flasks with 100 ml of fresh distilled water and add this solution to the 400 ml of solution to be analyzed. Then 400 ml of fresh distilled water was added to the sand to resume mixing during the next sampling period.

Sample filtering prior to analysis — It was found necessary to filter all samples through 0.10-micron filter prior to analysis.

Sampling period or interval — The time between sampling periods was found to be unimportant. Of greater importance is the total quantity of water used or the number of elutions. Only three sampling periods or elutions should be used due to possible excess stress on sand particles and unpredictability of results beyond three elutions.

Effect of silica on test results — Silica was not found to contribute significantly to matter release.

Differences in sand waste material — For molding sand containing bentonite, it was found necessary to centrifuge samples prior to filtering and analysis. This extra step is discussed later.

Reproducibility of results — Reproducibility of test results was examined during standardized testing procedure development. This examination is discussed in more detail in chapter 3 but appropriate curves from chapter 3 have been reproduced and presented in Fig. 6 and 7 to emphasize the findings of reproducibility evaluation. Cumulative COD curves are presented here for the third and fifth phases of testing. Sample replicates were run for different sand-water combinations. Significant reproducibility is demonstrated in sample replicates for both shell sand samples used in the third phase and molding sand samples used in the fifth phase. The method of sample selection and preparation was found to be an important factor in obtaining reproducibility of release. This is discussed briefly above and in more detail in chapter 3.

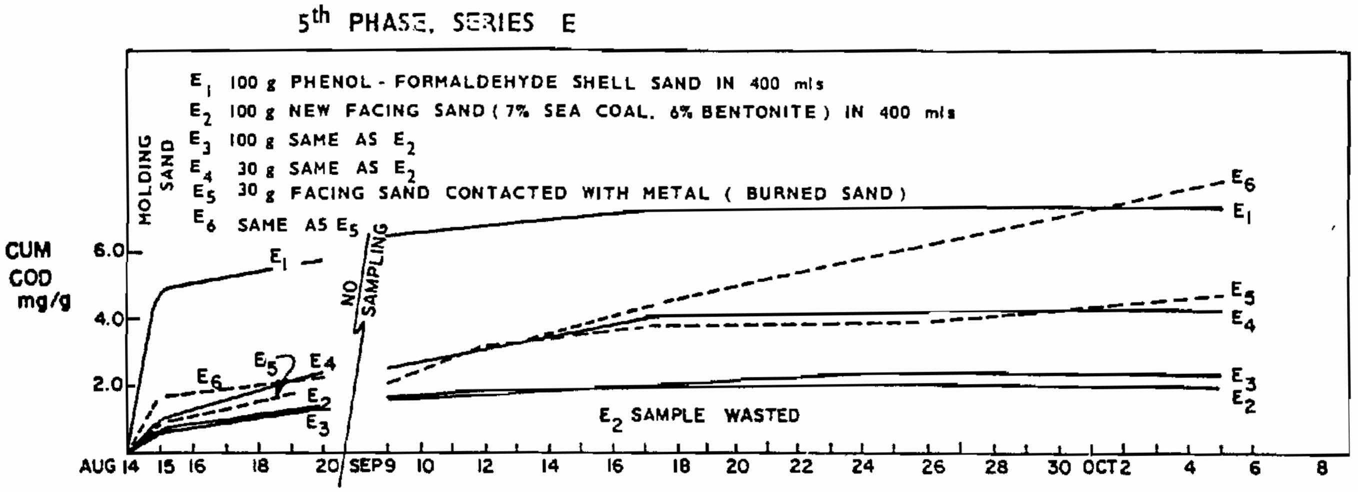


Fig. 6. Cumulative COD vs sampling days with shell sand and molding sand.

A more detailed discussion of test phases which examined these variables and which led to development of the standardized procedure is included in chapter 3.

Standardized Test Procedure

Based on procedures and results of several phases of testing, the following procedure is recommended for shake-flask tests to determine matter release from foundry sand materials:

1) Sand to be tested must be mixed and split to provide selection of representative samples.

2) Duplicate samples of 100 g of sand in 400 ml of distilled water should be prepared for each type of test material.

3) Samples should be placed in wide-mouthed containers.

4) A reciprocating shaker can be used for sand-water mixing but should be operated intermittently (i.e. 15 sec of shaking twice daily). An alternate mixing method using low-speed continuous stirring is also acceptable.

5) Sampling should be conducted through a total of three elutions for each test material. This should provide sufficient data to develop release curves. Additional elutions and samplings can create excessive stress on sand particles and cause scattering of the release curves.

6) A reasonable sampling frequency can include sampling and analysis at the ends of the first, third and fifth or sixth days of shaking, but for a total of only three elutions. Since it appears that approximately the same release occurs with one day of shaking as occurs with several days, sampling and elution can also be done as frequently as once per day.

7) At each sampling period, all water should be removed from the samples.

8) Water removed from samples containing clay material should be centrifuged prior to filtering and analysis.

9) Prior to analysis, sample water should be filtered through a 0.10-micron-size filter.

10) After filtering the 400 ml of sample water, solid residue remaining in the flasks should be rinsed with 100 ml of fresh distilled water. This water also should be filtered so that the filtrate will then include a total of 500 ml of sample water.

11) Any solid material remaining in the bottom of centrifuge tubes or on filter pads after filtering should be rinsed back into the shake flasks with fresh distilled water. Additional fresh water should be placed in the flasks to return the total volume to 400 ml. The shaking procedure for these flasks can then be resumed for the next sampling period.

12) The filtered sample water can be analyzed for various constituents according to standard wet chemical methods, emission spectroscopy and any other applicable methods.

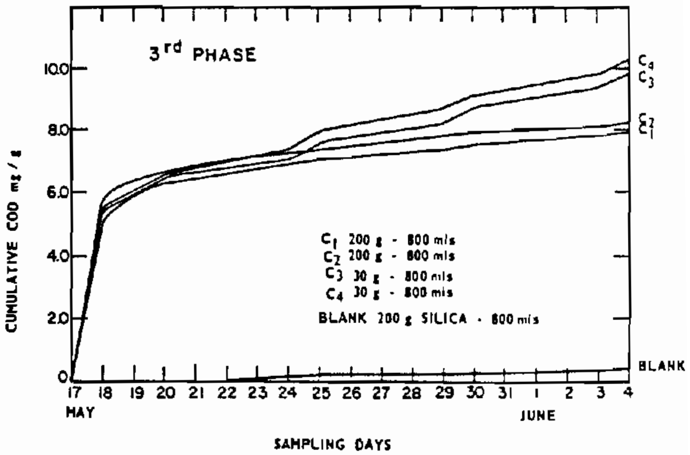


Fig. 7. Cumulative COD vs sampling days with shell sand.

Results of Preliminary Studies

The standardized laboratory testing procedure discussed above was used to examine leaching characteristics of several types of foundry sand materials. Selection of materials to be examined was based on concensus view of the American Foundrymen's Society Committee responsible for monitoring progress on this research project plus the University of Wisconsin Metallurgical and Mineral Engineering Department.

Materials were selected to be broadly representative of many core and system sands used in the foundry industry. Seven types of core sands were prepared including a precoated 4% phenol formaldehyde shell sand, a 4% sodium silicate/CO_2 sand, a 1% oil sand containing 1% cereal, a 1.26% phenolic isocyanate sand, a 1.91% alkyd isocyanate sand, a 2.4% furan resin hot box sand and a 2.4% furan resin nobake sand. In addition, a molding sand containing 6% western bentonite and 7% seacoal was also prepared.

It has been observed through work by Santa Maria[5] that volatile content in resins of various foundry sands decreases when the sand is subjected to foundry process temperature levels. Temperature degradation curves for each sand showed that volatile-content levels and reduction rates varied for different sands tested. These findings led to the premise that matter release in water, or leaching potential, of a sand containing a certain resin could depend in part on temperatures to which sand is subjected in foundries. In order to investigate this factor and examine its effects, each of the eight sands was subjected to several temperature levels prior to testing. Temperature levels selected were based on temperature degradation studies. Sands were then prepared for leaching studies at temperature levels representative of selected portions of the temperature degradation curves. A portion of each of the eight sands was prepared according to Table 12.

All sands except the uncured and cured (400-500F (204-260C)) phenol formaldehyde shell sands and the molding sands were crushed in a roll crusher. The cured shell sand was crushed in a ball mill for 1 hr. Details of sand preparation techniques and temperature degradation curves have been reported by Santa Maria.[2] In addition to the determination of release curves for various sands, leachate samples were also tested for various other parameters of water quality including:

Metals — by emission spectroscopy

Phenol — pretreatment by distillation was performed, followed by the chloroform extraction method.[15]

Cyanide — silver nitrate titration method. The distillation process[17] was used as a preliminary treatment procedure, isolating cyanide from most interferences and converting most cyanide complexes into the simple ion CN^- that is readily measured by titration or color test.

Table 12. Sands Prepared for Testing

Sand 1 — Phenol Formaldehyde
Not subject to process temperatures
400-500F (750-930C)
900F (1650C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 2 — Oil Sand
Not subject to process temperatures
450F (840C)
800F (1470C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 3 — Phenolic Isocyanate
Not subject to process temperatures
700F (1300C)
1000F (1830C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 4 — Furan Nobake
Not subject to process temperatures
400F (750C)
1100F (2000C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 5 — Sodium Silicate - CO_2
Not subject to process temperatures
300F (570C)
700F (1300C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 6 — Furan Hot Box
Not subject to process temperatures
450F (840C)
900F (1650C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 7 — Alkyd Isocyanate
Not subject to process temperatures
300F (570C)
900F (1650C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Sand 8 — Molding Sand
Not subject to process temperatures
600F (1110C)
900F (1650C)
1100F (2000C)
1800F (3270C)
Contacted with molten metal 2700F (4900C)

Test Results

Release Curves for All Sands

Results of tests conducted on the eight sands at various temperature levels are shown as cumulative release curves in Fig. 8-38. All data is presented for the eight sands without discussion at this point. Results have been normalized on a "milligram of release per gram of sand" basis. Solids data is not plotted because of the low levels tested and lack of discernable trends in solids release. In addition, solids release appeared to be a function of sand and resin attrition which varies with different sands.

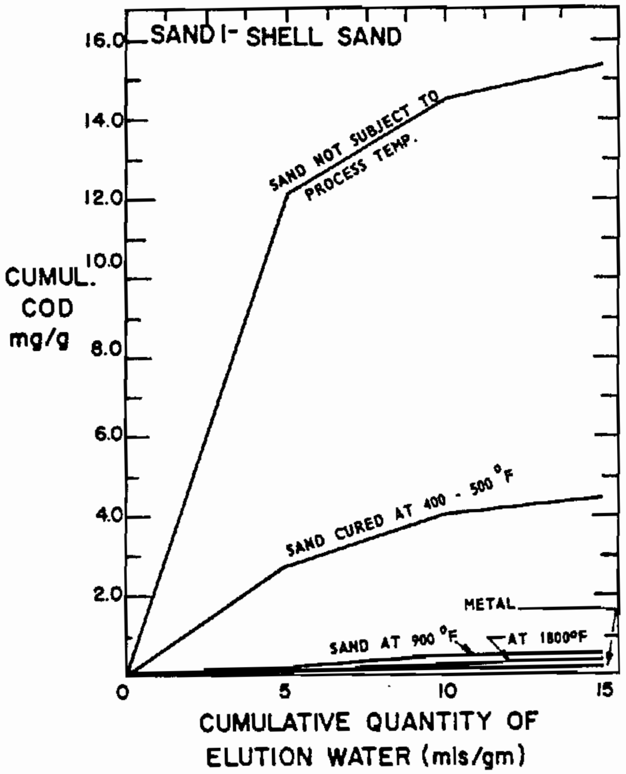


Fig. 8. Sand 1 — cumulative COD vs cumulative quantity of elution water.

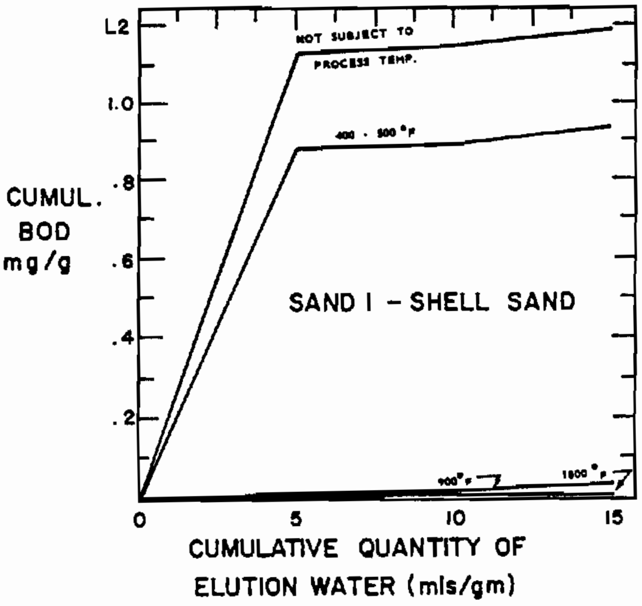


Fig. 9. Sand 1 — cumulative BOD vs cumulative quantity of elution water.

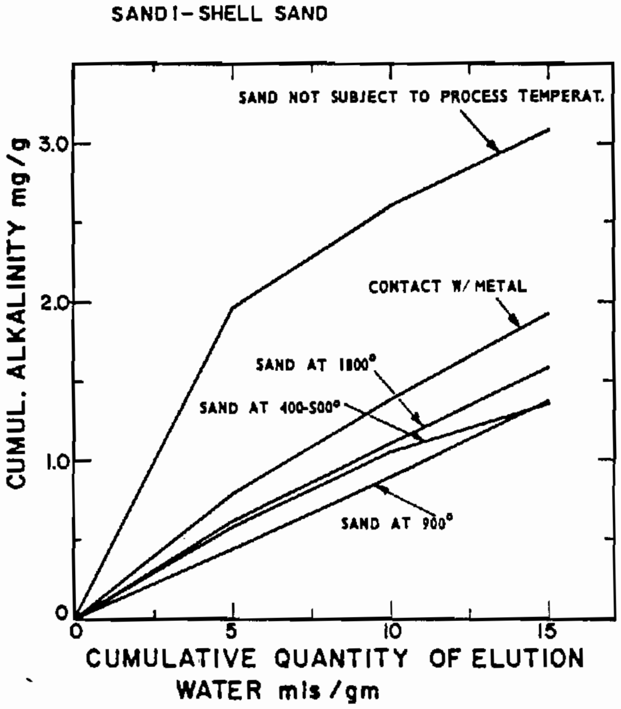


Fig. 10. Sand 1 — cumulative alkalinity vs cumulative quantity of elution water.

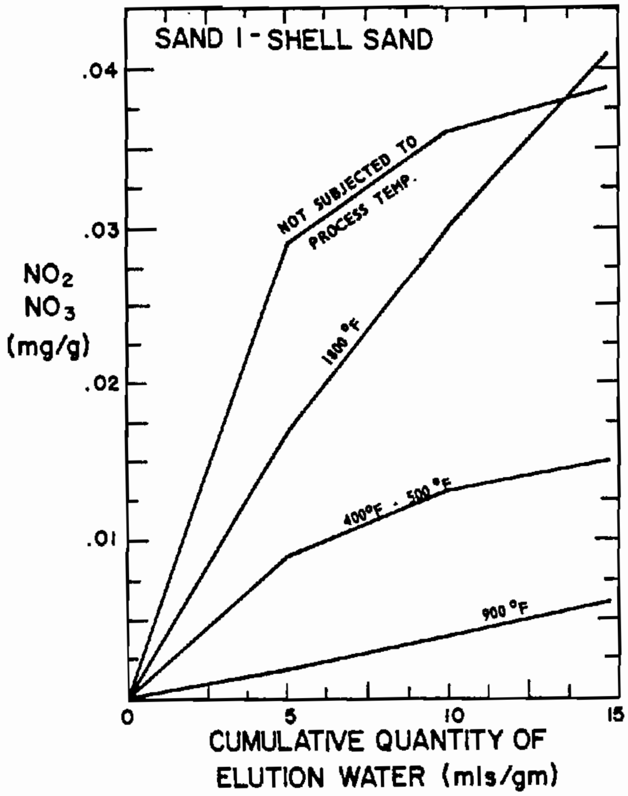


Fig. 11. Sand 1 — cumulative NO_2-NO_3 vs cumulative quantity of elution water.

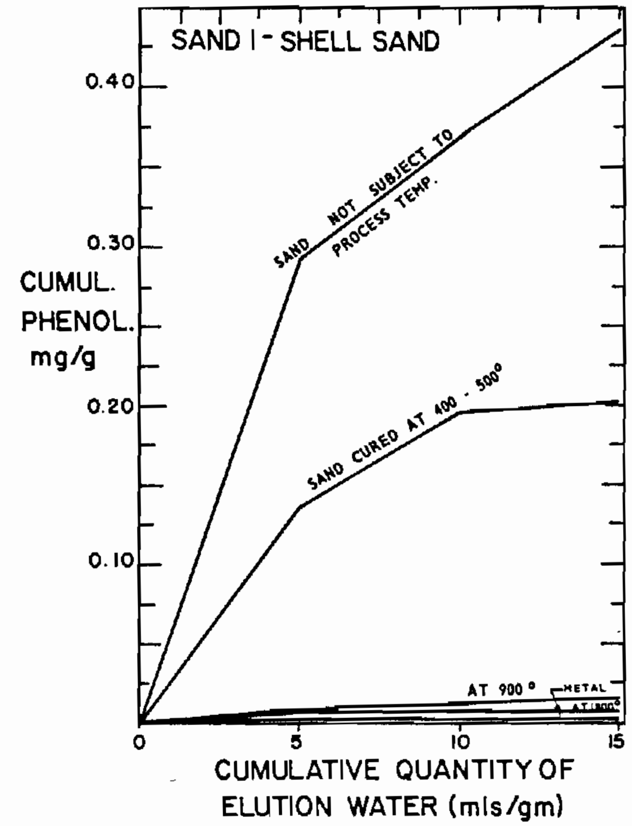


Fig.12. Sand 1 — cumulative phenol vs cumulative quantity of elution water.

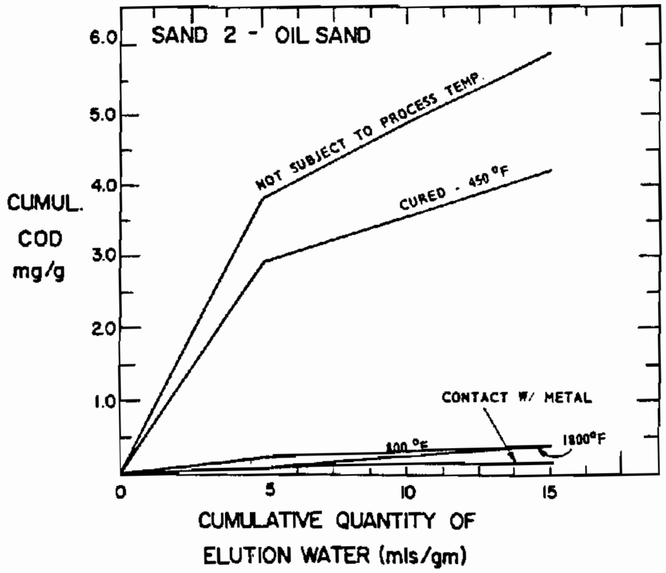


Fig. 13. Sand 2 — cumulative COD vs cumulative quantity of elution water.

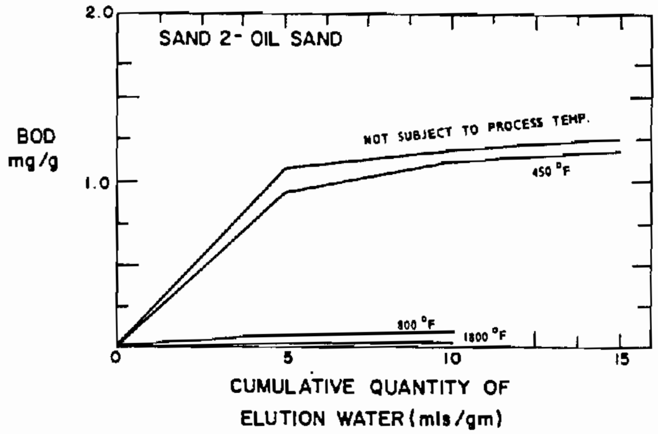


Fig. 14. Sand 2 — cumulative BOD vs cumulative quantity of elution water.

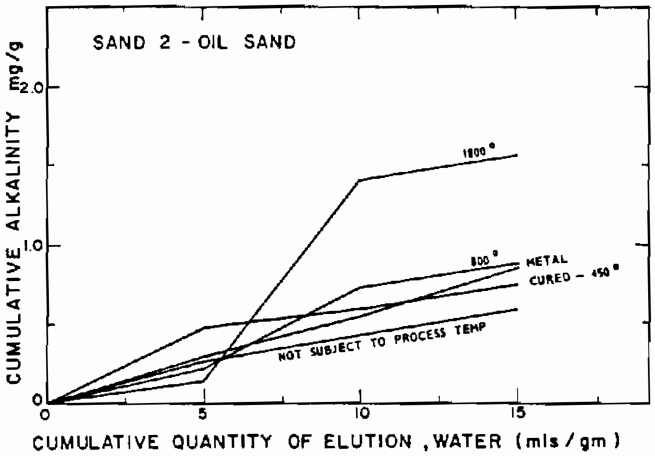


Fig. 15. Sand 2 — cumulative alkalinity vs cumulative quantity of elution water.

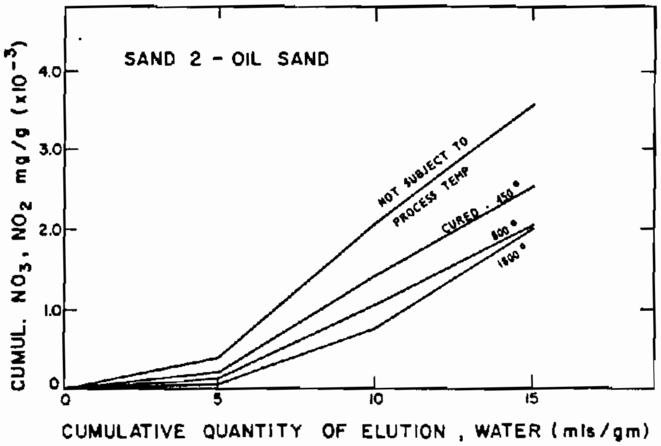


Fig. 16. Sand 2 — cumulative NO_2-NO_3 vs cumulative quantity of elution water.

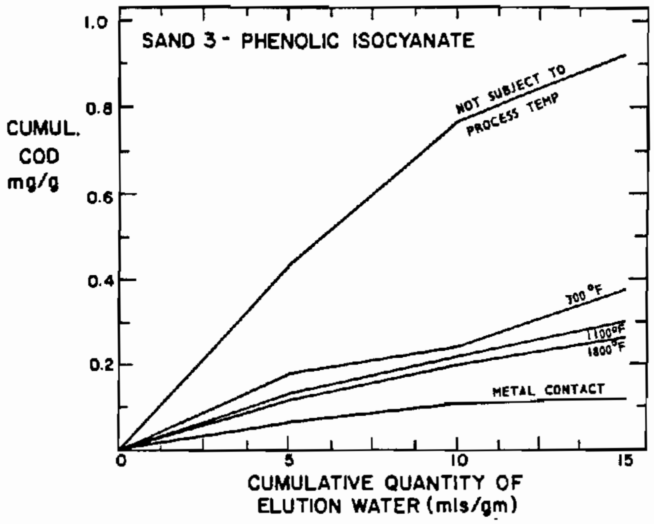


Fig. 17. Sand 3 — cumulative COD vs cumulative quantity of elution water.

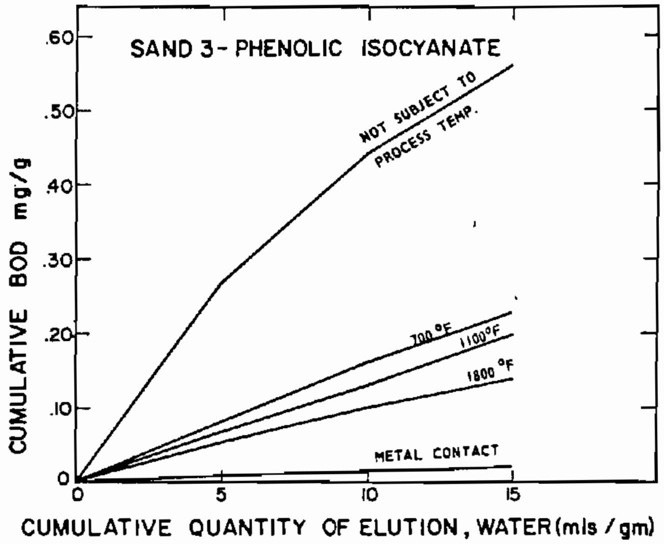


Fig. 18. Sand 3 — cumulative BOD vs cumulative quantity of elution water.

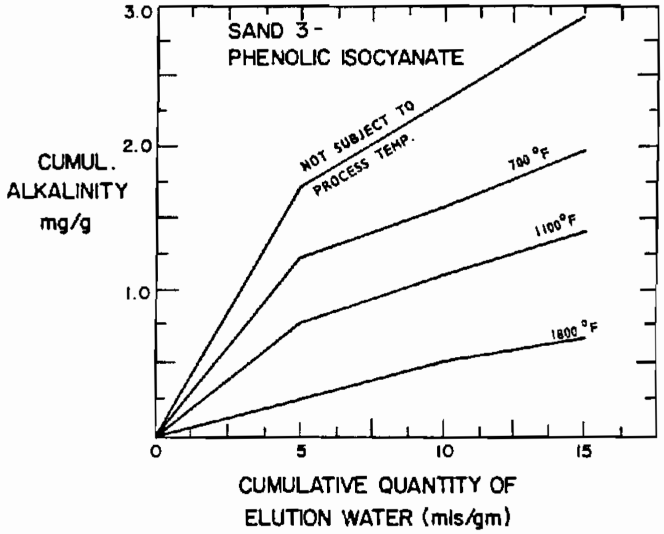


Fig. 19. Sand 3 — cumulative alkalinity vs cumulative quantity of elution water.

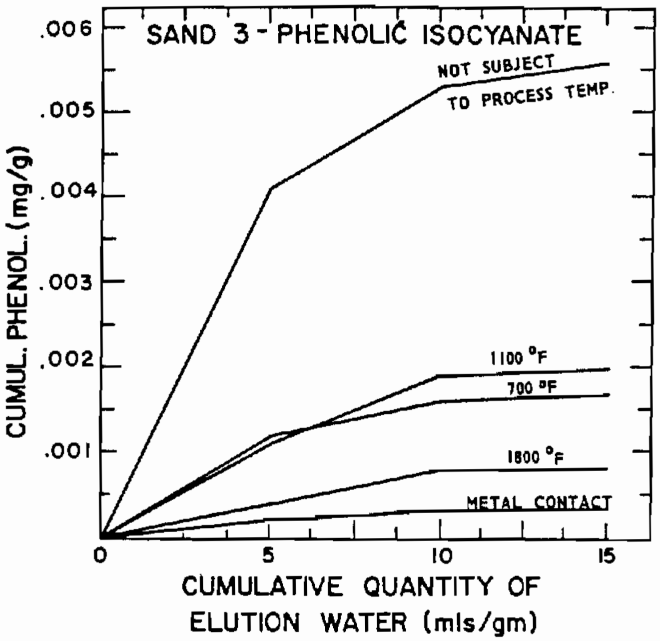


Fig. 20. Sand 3 — cumulative phenol vs cumulative quantity of elution water.

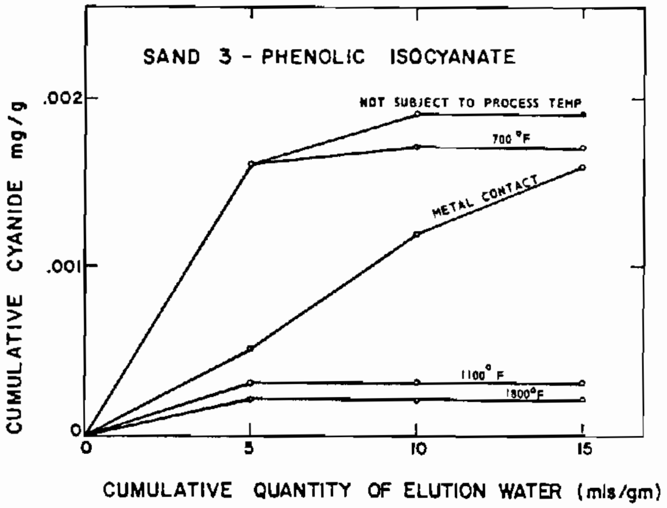


Fig. 21. Sand 3 — cumulative cyanide vs cumulative quantity of elution water.

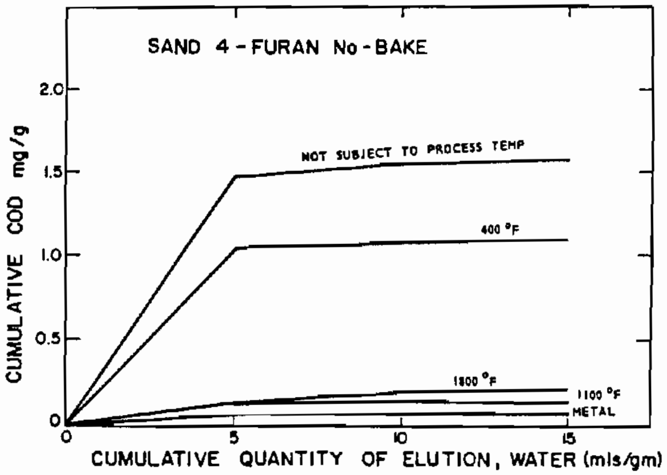


Fig. 22. Sand 4 — cumulative COD vs cumulative quantity of elution water.

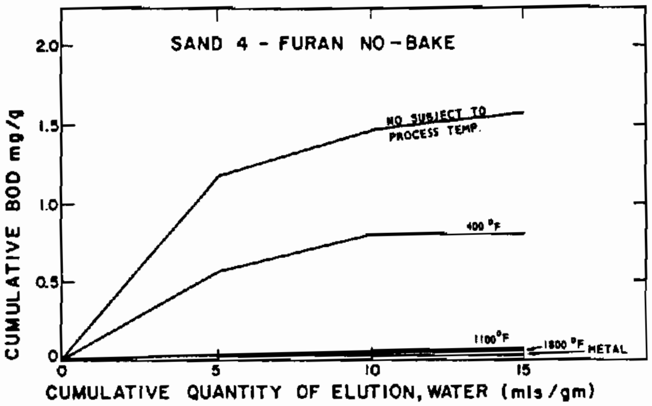


Fig. 23. Sand 4 — cumulative BOD vs cumulative quantity of elution water.

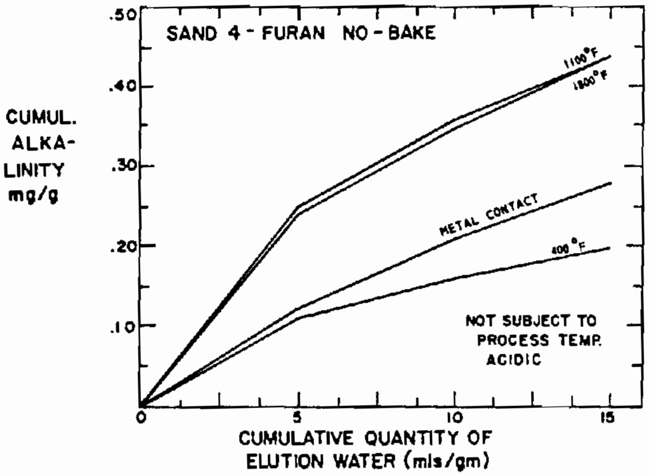


Fig. 24. Sand 4 — cumulative alkalinity vs cumulative quantity of elution water.

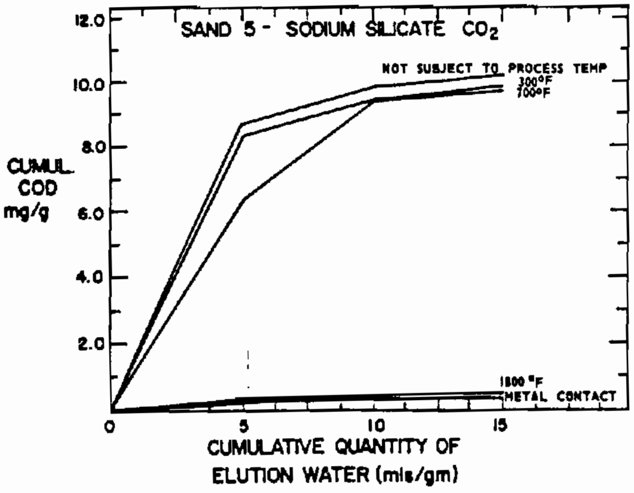


Fig. 25. Sand 5 — cumulative COD vs cumulative quantity of elution water.

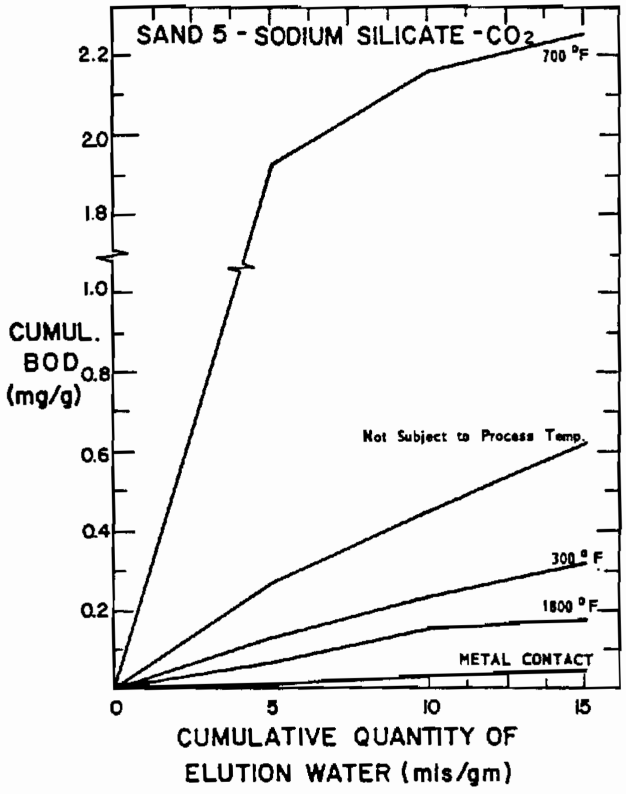


Fig. 26. Sand 5 — cumulative BOD vs cumulative quantity of elution water.

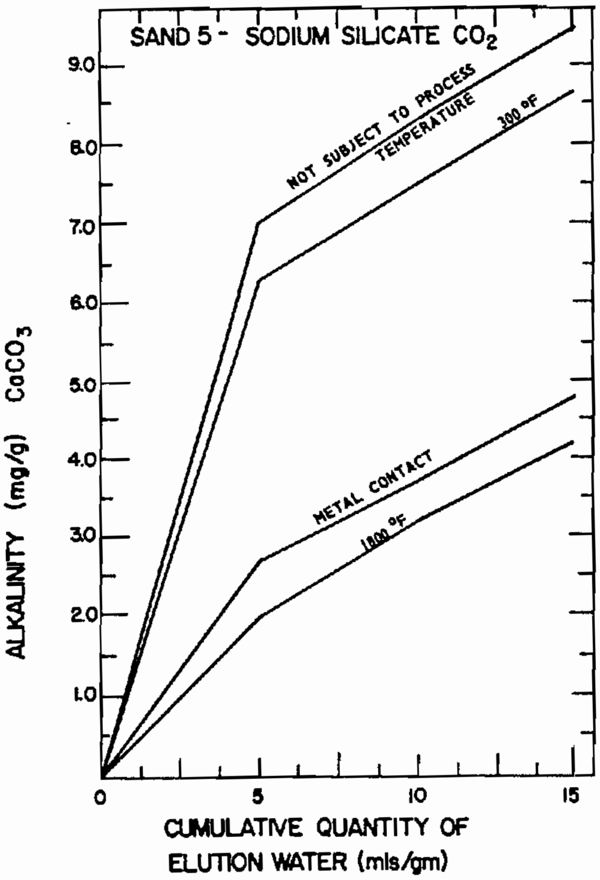


Fig. 27. Sand 5 — cumulative alkalinity vs cumulative quantity of elution water.

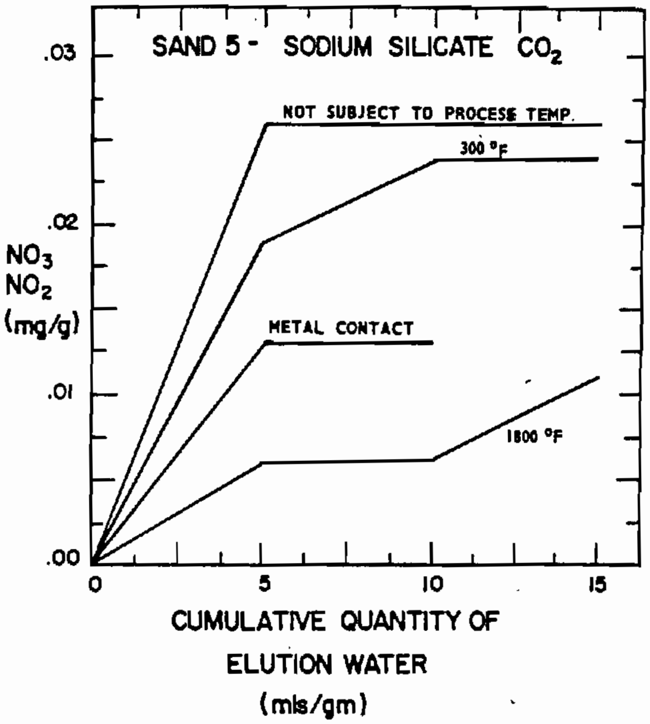


Fig. 28. Sand 5 — cumulative No_2-No_3 vs cumulative quantity of elution water.

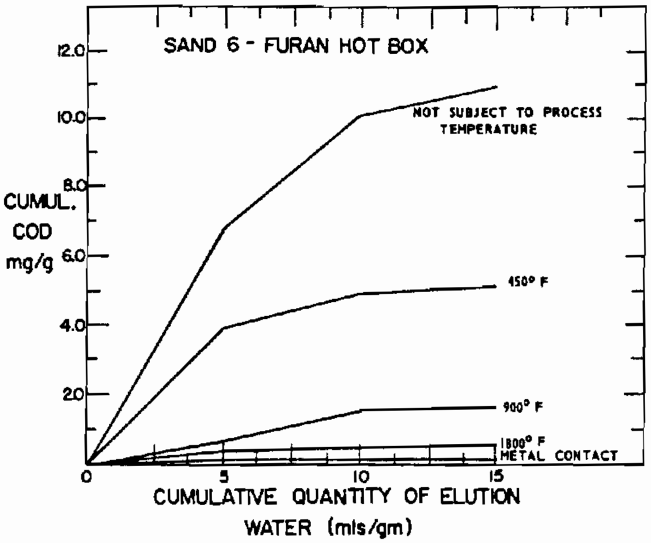


Fig. 29. Sand 6 — cumulative COD vs cumulative quantity of elution water.

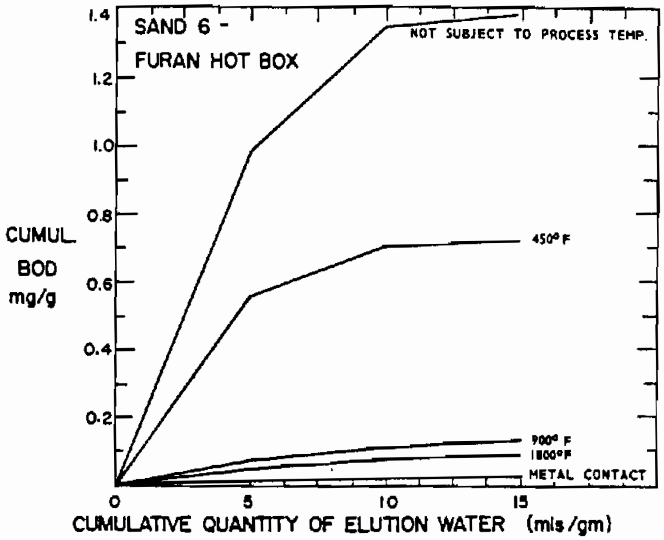


Fig. 30. Sand 6 — cumulative BOD vs cumulative quantity of elution water.

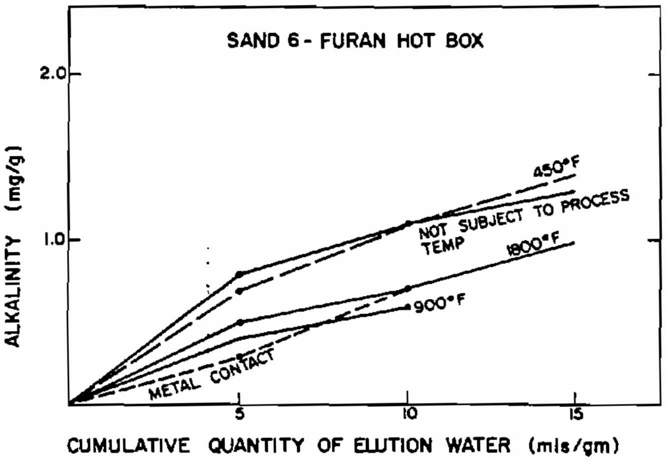


Fig. 31. Sand 6 — cumulative alkalinity vs cumulative quantity of elution water.

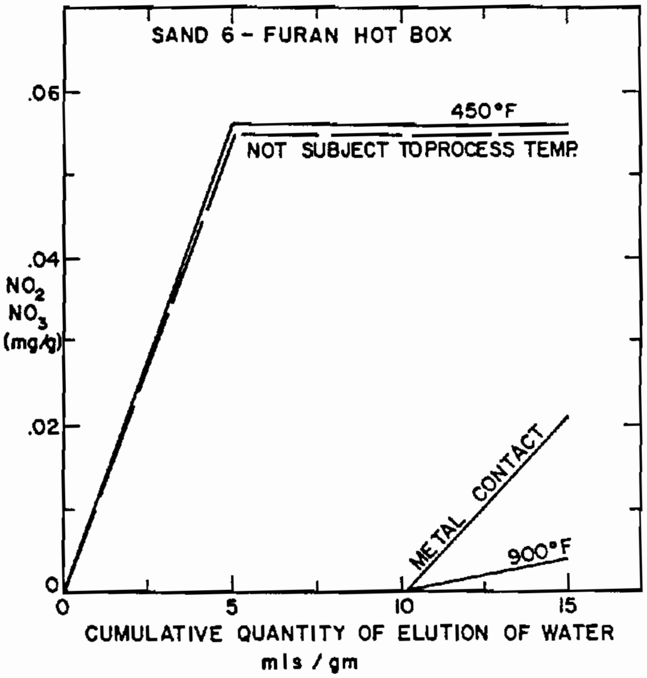


Fig. 32. Sand 6 — cumulative NO_2-NO_3 vs cumulative quantity of elution water.

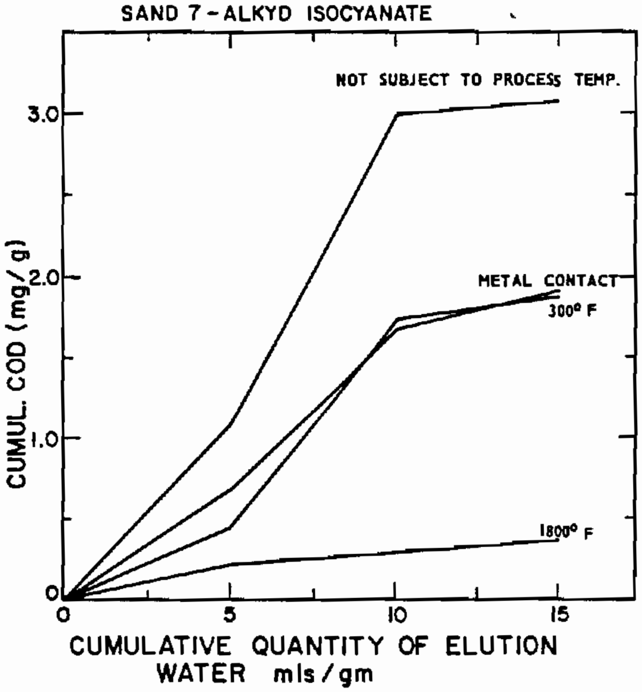


Fig. 33. Sand 7 — cumulative BOD vs cumulative quantity of elution water.

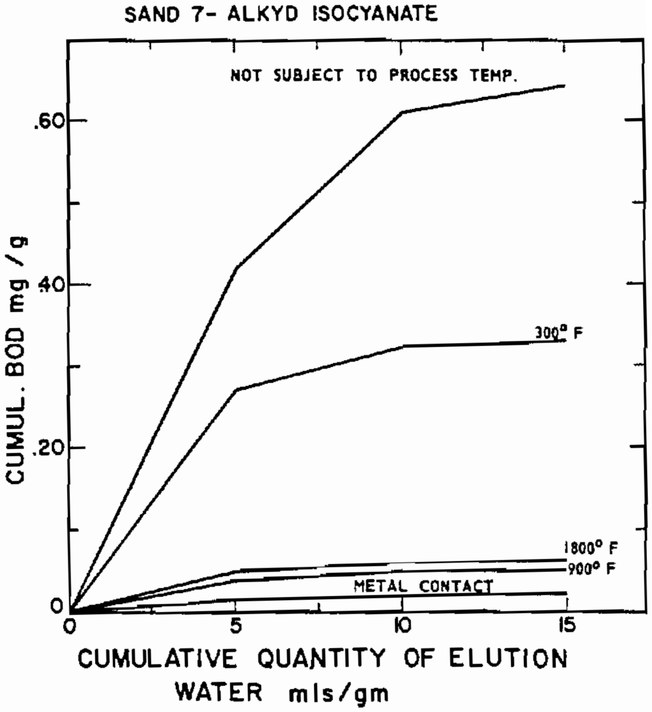


Fig. 34. Sand 7 — cumulative BOD vs cumulative quantity of elution water.

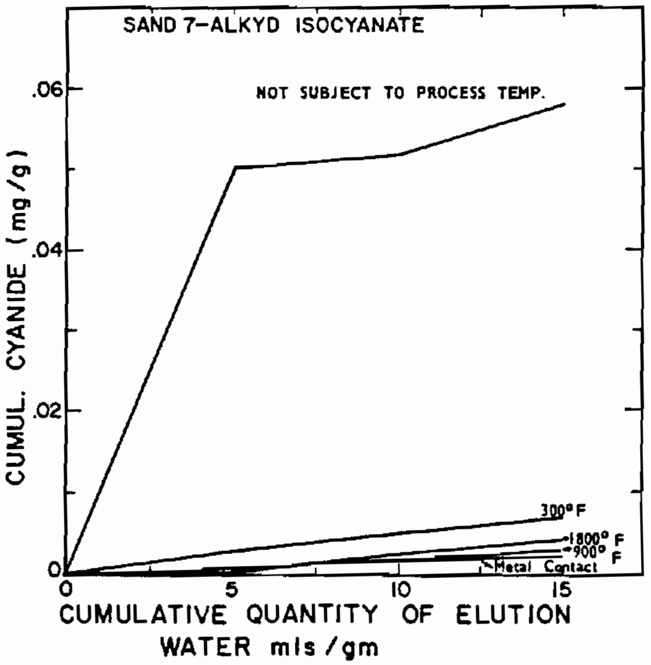


Fig. 35. Sand 7 — cumulative cyanide vs cumulative quantity of elution water.

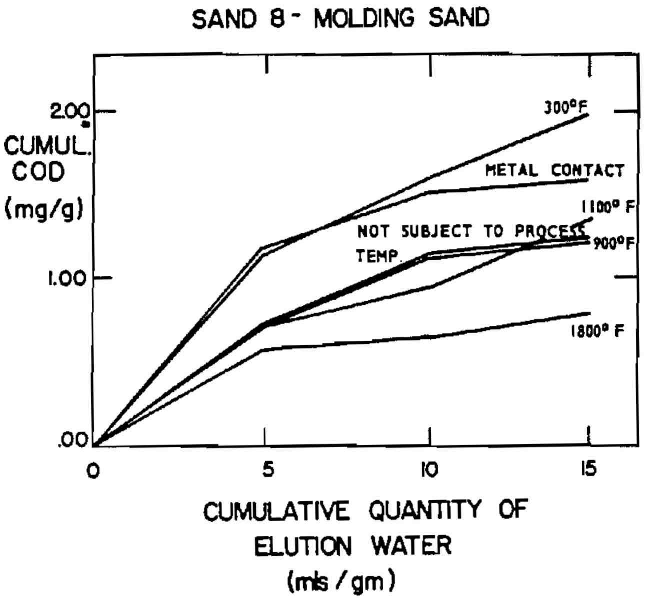


Fig. 36. Sand 8 — cumulative COD vs cumulative quantity of elution water.

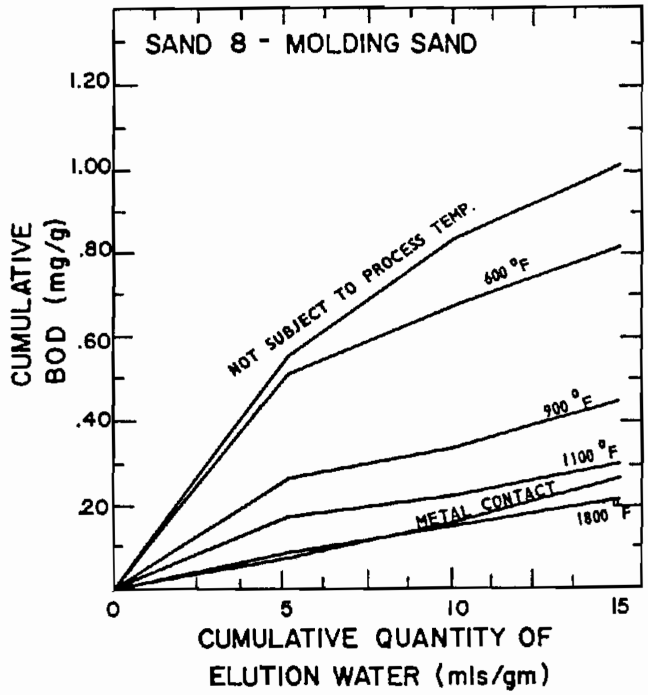


Fig. 37. Sand 8 — cumulative BOD vs cumulative quantity of elution water.

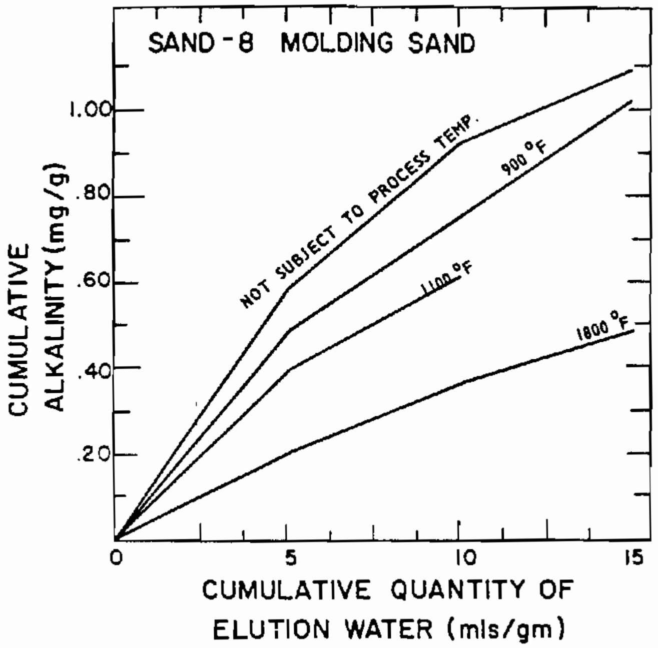


Fig. 38. Sand 8 — cumulative alkalinity vs cumulative quantity of elution water.

Cumulative Metals Release Data for All Sands

Metals release data is presented in Table 13 according to high, 2nd high and low release values for each sand. High values signify maximum cumulative release level of a particular sand after the third elution and do not relate to temperature to which a sand had been subjected. 2nd high values signify next-to-maximum cumulative release level after the third elution. Low release values signify minimum cumulative release level of a particular sand after the third elution. This was done in recognition of observations that for other parameters analyzed, the high value release, next high value and low value generally corresponded to temperature levels to which sands were subjected. Throughout the eight sands tested, metals analyses showed few trends in release. Most metals analyses indicated release levels too low to allow presentation or even development of release curves. In addition, no temperature degradation-release relationship was apparent.

Test Characteristics

From examination of data and curves (Fig. 8-38), it is found that the standardized testing procedure provides reproducible results. Release curves were developed through use of average release values for sample replicates. Throughout all eight sands, two individual release values within a single set of replicates varied approximately 5-10% from averaged plotted values in a majority of cases. The maximum variation was found to be slightly less than 20% from average. In general, BOD produced the greatest variation.

Table 13. Metals Release Data

	Cumulative Na(mg)/g	Cumulative Al(mg)/g	Cumulative Fe(mg)/g	Cumulative Cu(mg)/g	Cumulative Zn(mg)/g	Cumulative P(mg)/g	Cumulative Mn(mg)/g
Sand 1-Phenol Formaldehyde							
High	.155(2)	.019(1)	<.007(1)	.001(2)	.0008(1)	<.075	<.0006
2nd High	.052	.016	<.004(2)	.0006(1)	.0007	<.075	<.0006
Low	.042	.002(2)	<.002	<.0004	<.0003(2)	<.075	<.0006
Sand 2-Oil							
High	.111(2)	.022	.060(1)	.0015(1)	.005(1)	<.075	<.0006
2nd High	.085(1)	.020(1)	.048	.0014	.002	<.075	<.0006
Low	.062	.001(2)	.001(2)	.0008(2)	.0003(2)	<.075	<.0006
Sand 3-Phenolic Isocyanate							
High	.133(1)	<.0036	.026(2)	.001(1)	.0009(1)	<.093	<.00075
2nd High	.116	<.0036	.003	.001	.0008	<.093	<.00075
Low	.104	<.0036	.002(1)	.0007(2)	<.0003	<.093	<.00075
Sand 4-Furan No Bake							
High	.150(1)	.016	.046(1)	.0022	.0029(1)	<.093	<.00075
2nd High	.147	.007(1)	.024	.0019(1)	.0022	<.093	<.00075
Low	.095(2)	.004(2)	.002(2)	.0007(2)	.0006(2)	<.093	<.00075
Sand 5-Sodium Silicate-CO_2							
High	4.10(1)	.016(2)	.0034(1)	.0014	<.00036	<.093	<.00075
2nd High	3.3	.015	.0002(2)	.0009	<.00036	<.093	<.00075
Low	1.04	.007	.002	.0005(2)	<.00036	<.093	<.00075
Sand 6-Furan Hot Box							
High	.126	.032(1)	.0357	.0021	.0027	<.093	<.00075
2nd High	.105	.031	.162(1)	.0016(1)	.0021(1)	<.093	<.00075
Low	.064(1)	.017(2)	.0027	.0008(2)	.0005	<.093	<.00075
Sand 7-Alkyd Isocyanate							
High	.059(2)	.017(2)	.0072	.0010(1)	.0024	<.093	<.00075
2nd High	.048	.015	.0062(1)	.0009(2)	.0021(1)	<.093	<.00075
Low	<.036(1)	.013(1)	.0021	.0005	.0012	<.093	<.00075
Sand 8-Molding							
High	.56 (1)	.026	.0150	.0011	.0012	<.093	<.00075
2nd High	.36	.025(1)	.0031(1)	.0011	.0012	<.093	<.00075
Low	.32	.022	.0030	.0011	.0011(1)	<.093	<.00075

	Cumulative K(mg)/g	Cumulative Ca(mg)/g	Cumulative Mg(mg)/g	Cumulative Ba(mg)/g	Cumulative Sr(mg)/g	Cumulative B(mg)/g	
Sand 1-Phenol Formaldehyde							
High	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
2nd High	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
Low	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
Sand 2-Oil							
High	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
2nd High	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
Low	<.30	<.150	<.03	<.0006	<.0003	<.0003	<.0009
Sand 3-Phenolic Isocyanate							
High	<.36	<.186	<.036	<.00075	.0016	.00078(2)	<.0011
2nd High	<.36	<.186	<.036	<.00075	.0014	.00077(1)	<.0011
Low	<.36	<.186	<.036	<.00075	.0009(2)	.00058	<.0011
Sand 4-Furan No Bake							
High	.66	<.186	<.036	<.00075	.0024	.00114(1)	<.0011
2nd High	.60	<.186	<.036	<.00075	.0022(1)	.00093	<.0011
Low	<.36(2)	<.186	<.036	<.00075	.0013	.00061(2)	<.0011
Sand 5-Sodium Silicate-CO_2							
High	<.30	<.186	<.036	<.00075	<.00036	<.00036	<.0011
2nd High	<.30	<.186	<.036	<.00075	<.00036	<.00036	<.0011
Low	<.30	<.186	<.036	<.00075	<.00036	<.00036	<.0011
Sand 6-Furan Hot Box							
High	<.36	<.186	<.036	<.00075	.00148	.00814	<.0011
2nd High	<.36	<.186	<.036	<.00075	.00122	.00692(1)	<.0011
Low	<.30	<.186	<.036	<.00075	.00076(2)	.00094(2)	<.0011
Sand 7-Alkyd Isocyanate							
High	.65	<.186	<.036	<.00075	<.00036	<.00036	<.0011
2nd High	.64(1)	<.186	<.036	<.00075	<.00036	<.00036	<.0011
Low	.53	<.186	<.036	<.00075	<.00036	<.00036	<.0011
Sand 8-Molding							
High	.90	<.186	<.036	<.00075	.00200	.00114	<.0011
2nd High	.90	<.186	<.036	<.00075	.00082(1)	.00088(1)	<.0011
Low	.89	<.186	<.036	<.00075	.00050	.00078	<.0011

NOTE: Metals data for sand #8 not available for samples subjected to 1800°F and to molten metal
(1) = Sand not subject to process temperature (2) = Sand contacted with molten metal

Use of three periods of testing (three elutions) enabled development of well-defined release curves. Maximum release of matter generally occurred during the first sampling period. Release curves generally flattened or leveled off after the first sampling period. This indicates incrementally less release during second and third sampling periods than during the first.

This is felt to occur from release of matter primarily at the surface of resin on sand particles. Susceptibility of matter to be released into water appears to be decreased after the more readily available surface coating has been released. Hence, the first elution results in largest matter release.

Release of Various Substances

The highest COD levels were released from phenol-formaldehyde shell sand. The highest BOD levels were obtained from furan hot box sand. For all sands tested, it was observed that maximum BOD levels were at or below maximum COD levels. Table 14 shows COD/BOD ratios for sands not subjected to process temperatures.

The high degree of variation among COD/BOD ratios in Table 14 could be due to varying degrees of toxicity to microorganisms of some materials. It might be expected that sand with highest COD/BOD ratios in these cases could present the greatest toxicity conditions for BOD testing. Sawyer and McCarty[19] indicated experience with the relatively high toxicity of both phenol and formaldehyde.

COD and BOD release were observed to be in accordance with general test characteristics discussed above. Results were reproducible, with three elutions providing well-defined release curves. Maximum release of COD and BOD generally occurred in the first elution. Curves flattened after the first elution indicating incrementally less release during the second and third.

Comparisons of COD and BOD values among all sands are shown in Fig. 39 and 40.

An initial test objective was to compare actual release of matter, particularly COD, with total theoretical levels calculated to be present in resins based on information sought concerning chemical makeup of the resins. It was felt that such comparisons would give some data concerning relative leachability or solubility of the various resins. Comparisons were to be made between calculated levels and analytical test levels for sands not subjected to process temperatures.

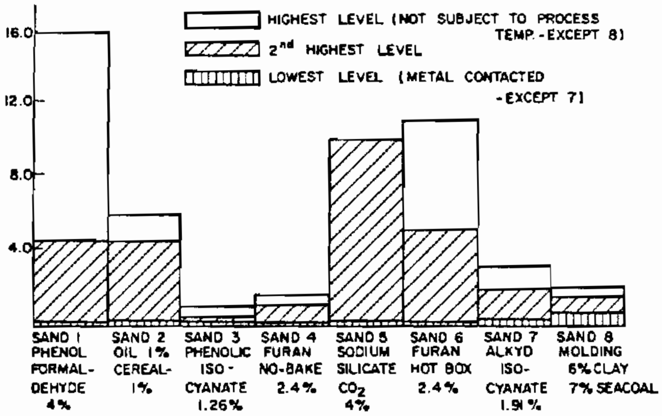


Fig. 39. Cumulative COD for all sands tested.

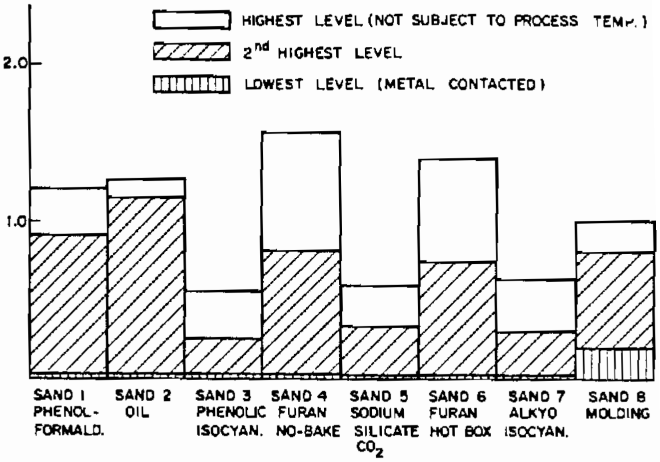


Fig. 40. Cumulative BOD for all sands tested.

Due to inability to obtain adequate chemical composition information from most resin manufacturers, COD was calculated only for phenol-formaldehyde shell sand. Phenol was also calculated for shell sand and is discussed later.

Phenol and formaldehyde are reacted with a catalyst(s) to form a compound which can exist in several forms, para, meta or ortho hydroxy phenol. For purposes of this report and the following COD calculations, the particular form of the compound was not expected to be significant. Since theoretical COD is the oxygen consumed by total oxidation of a given material under chemical reaction, an oxygen balance can be performed to estimate the theoretical COD of a given compound:

$$C_6H_4\text{-OH-CHO} + 7\text{-}1/2\,O_2 = 7CO_2 + 3\,H_2O$$

Molecular weight of resin (C_6H_4-OH-CHO)

carbon	(7 x 12) = 84
hydrogen	(6 x 1) = 6
oxygen	(2 x 16) = 32
	122

Molecular weight of 7-1/2 O_2

oxygen	(15 x 16) = 240

Table 14.

Sand	COD/BOD Ratio
Phenol-formaldehyde	12.5
Oil sand	4.8
Phenolic isocyanate	1.6
Furan nobake	1.0
Sodium silicate-CO_2	4.5
Furan hot box	7.9
Alkyd isocyanate	5
Molding sand	1.3

For each gram of C_6H_4-OH-CHO, 240/122 or 1.97 g of oxygen is needed for oxidation.

Hence, for sand containing a range of 2.0-2.8% phenol-formaldehyde resin (see phenol calculations), or 0.020-0.028 g resin/g of sand, oxygen requirements for total oxidation would range from:

(1.97) x 0.02 = 0.039 to (1.97) x 0.028 = 0.055 or 39 to 55 mg oxygen/g of sand.

Therefore, examination of the COD obtained in test results (Fig. 8) indicates that approximately 1/3 of the theoretical COD was actually released from the sand not subjected to process temperatures.

This result could be due to relatively low solubility of the resin, polymerization of the resin to some extent at normal room temperature and release of matter primarily from the surface of the resin coating.

Nitrated nitrite release generally showed the same shape release curves as for other parameters, with greatest release occurring during the first elution and for sands not subjected to process temperatures. Nitrogen compounds are, at times, made a part of the resin as catalysts. NH_4NO_3 is sometimes used during curing of sands.

Alkalinity differed somewhat from other parameters in release curve shape by producing generally steeper slopes (i.e. greater increases) for release from the second and third elutions. Alkalinity curves did not level off substantially from these elutions, indicating additional time or contact with water needed for alkalinity to be released.

Alkalinity curves in some cases showed relatively high levels for sand subjected to high process temperatures. This is probably a result of oxide formation during the heating process which hydrolyzes to form hydroxides. The hydrolysis reactions may be rate-limiting in the release of alkalinity during shake-flask testing, giving rise to the longer period of mixing required to release alkalinity when compared with organic matter.

Release of phenol from phenol-formaldehyde shell sand was significantly higher than release of phenol from phenolic-isocyanate sand. This difference may be due to different amounts of total resin present in the sands (4% in shell sand, 1.26% in phenolic-isocyanate) or relative amounts of phenol present in the resins, as well as the form of phenol. Approximate calculations have been made for total phenol in shell sand not subjected to process temperature. As with theoretical COD calculations given earlier for shell sand, information on chemical composition of the resin was obtained from the manufacturer and through consultation with the Mineral and Metallurgical Engineering Department at U.W.

According to correspondence from the resin manufacturer, a 1:1 molecular ratio of phenol (C_6H_5-OH) and formaldehyde (CH_2O) can be used.

Molecular weight of phenol (C_6H_5-OH)

carbon:	(6 x 12) = 72
hydrogen:	(6 x 1) = 6
oxygen:	(1 x 16) = 16
	94

Molecular weight of formaldehyde (CH_2O)

carbon:	(1 x 12) = 12
hydrogen:	(2 x 1) = 2
oxygen:	(1 x 16) = 16
	30

On the basis of a 1:1 molecular ratio of the two compounds, the molecular weight of phenol-formaldehyde would be (94 + 30), or 124 with phenol comprising (94/124) x 100, or 76% by weight.

Resin used as a shell sand binder normally contains 50-70% phenol-formaldehyde. Therefore, a sand with 4% resin binder actually contains 2-2.8% phenol-formaldehyde, of which 76%, or 1.44-2.13%, is phenol.

On a per-gram of sand basis:

Phenol = 0.014-0.021 g/g, or 14-21 mg/g of sand

Therefore, based on examination of the phenol release curve for shell sand not subjected to process temperature (Fig. 12), release of 0.45 mg/g phenol would represent approximately 2-3% of total phenol present.

This indicates that only a small portion of phenol present is leached into the elution water, apparently due to polymerization of phenol resin to a limited extent at normal room temperature through time and possible release of phenol primarily from the surface of the resin coating of each sand particle. Inability to obtain adequate chemical composition information on phenolic-isocyanate resin prevented making phenol calculations similar to the type made for phenol-formaldehyde shell sand.

Results of cyanide analyses from alkyd-isocyanate sand showed higher cyanide levels than those from phenolic-isocyanate sand. This difference may relate to differences in total quantities of resin present in each sand, differences in the relative amount of cyanide or leachability of the cyanide. More resin was present in the alkyd-isocyanate sand than was found in the phenolic-isocyanate sand.

It should be noted that in analytical techniques used, cyanide complexes are converted to the simple CN^- ion. Curves and bar charts have been prepared in terms of CN^- levels. This does not mean that CN^- form of cyanide is obtained from the isocyanates tested here. Ludzack et al[20] evaluated cyanide interference from cyanate and thiocyanate using several analytical methods for cyanide testing. Tests using silver nitrate titration showed negligible cyanide recovery differences from coke waste with or without the addition of cyanate or thiocyanate. For their tests, distillation effectively separated both of these ions from cyanide. Their work tends to indicate in a preliminary way, that cyanide levels measured from phenolic isocyanate sand and alkyd isocyanate sand are not resulting from the isocyanate. Other constituents present in the resin could be possible sources of cyanide. However, no additional information was available from resin manufacturers or suppliers.

No water quality standards have been developed at this time for isocyanate discharge. Munn[21] indicates there are health hazards with air-borne isocyanates relating to respiratory problems.

Cyanide was felt to be the most applicable parameter for which to test at this point in the research. No specific analytical test procedure was found for isocyanate determination in water. However, Meddle and Wood[22] discuss a technique for determining aromatic isocyanate in air. The possibility of adapting the test technique for use in determining isocyanate in water was discussed with personnel from the State of Wisconsin, Laboratory of Hygiene.

While documentation was not found concerning interference effects of isocyanate on cyanide testing, a preliminary review of literature and discussion with various laboratory personnel indicates that isocyanate is not likely to contribute to cyanide being reported here for the two sands. Additional research on isocyanate considerations may be warranted.

Comparisons of phenol and cyanide results between sands are shown in Fig. 41 and 42.

Metals Release

Throughout the sands tested, metals analyses showed few trends in release. In some cases, metals release values were highest for sands not subjected to process temperatures and lowest for sands subjected to molten metal. However, this result did not occur with enough consistency to state it as a general conclusion.

Metals detected in the tests could come from several sources. They could be present in the sands themselves or in the resins, be introduced during the coremaking process or be introduced to the sand at the metal-sand interface during the casting and cooling process. One reason the sands subjected to molten metal were found to contain very low metal levels could be the relatively small amount of sand actually in intimate contact with the molten metal during pouring and casting.

With the many possible sources of metals that could be detected in the analytical tests, the wide fluctuations and lack of discernible release trends are not unexpected.

Effect of Temperature to which Sands Were Subjected

In general, release quantities for all sands were highly dependent upon the temperatures to which sands were subjected. Release of all matter (except metals) was significantly higher for sands not subjected to process temperatures as compared to sands subjected to a variety of process temperatures, including those ranging as high as 1800 and 2700F (982 and 1482C) during metal pours. In many cases, matter release for sands subjected to the next lowest temperature (i.e. curing temperature at levels of 300-700F (149-371C) depending on sand) was half the matter release from sand not subjected to any process temperatures.

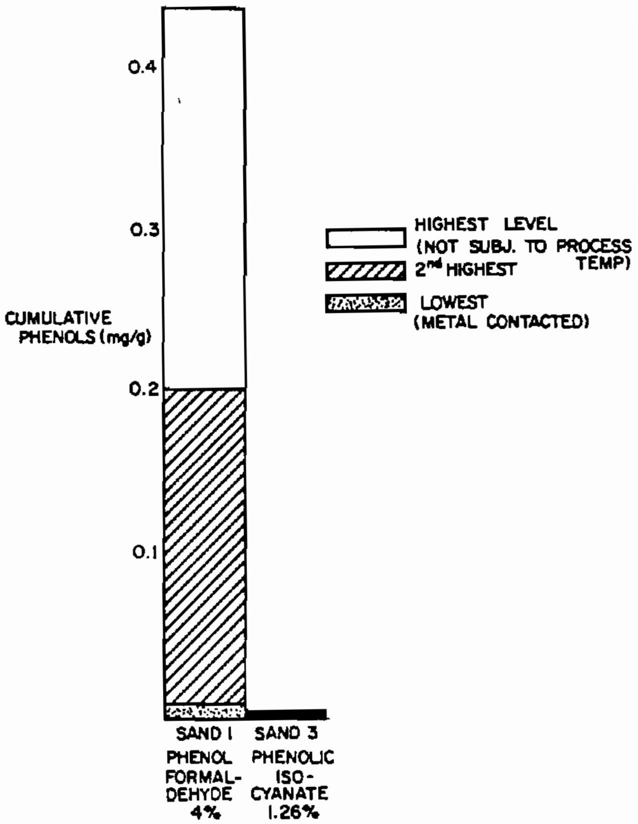


Fig. 41. Comparison of phenol release for sand 1 and sand 3.

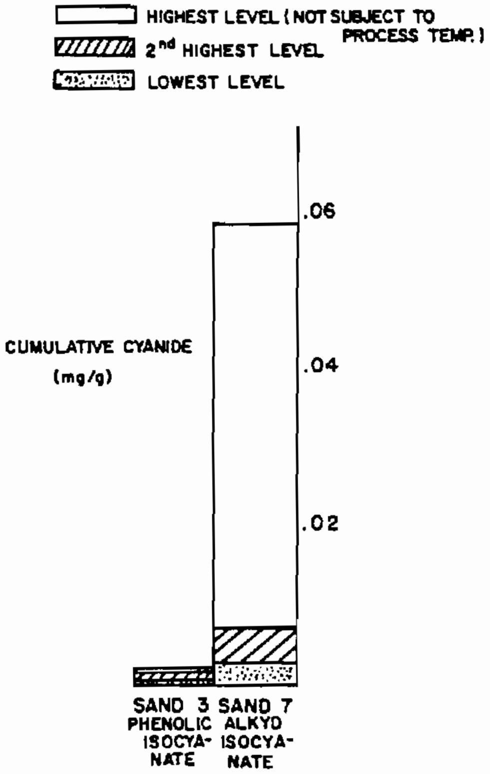


Fig. 42. Comparison of cyanide release sand 3 and sand 7.

During curing and other heat-intensive processes, resins undergo changes such as volatilization and polymerization. These changes are reflected in the shapes and values of release curves. Highest-level release occurs where least change to the resin has taken place (i.e. sand not subjected to process temperatures). Lowest-level release was found where the greatest change to the resin has occurred (i.e. sand subjected to metal pouring temperatures). In particular, phenol resins undergo polymerization during heating which is felt to make them less susceptible to release in elution water than when they are not subjected to process temperatures.

A report by the Association of Swedish Foundries[23] supports the conclusion that exposure of sand to heat has an important effect on leaching of matter. The report discusses different disposal methods for heat-treated vs non-heat-treated sand containing phenol. Higher leaching potential was recognized for the non-heat-treated sand.

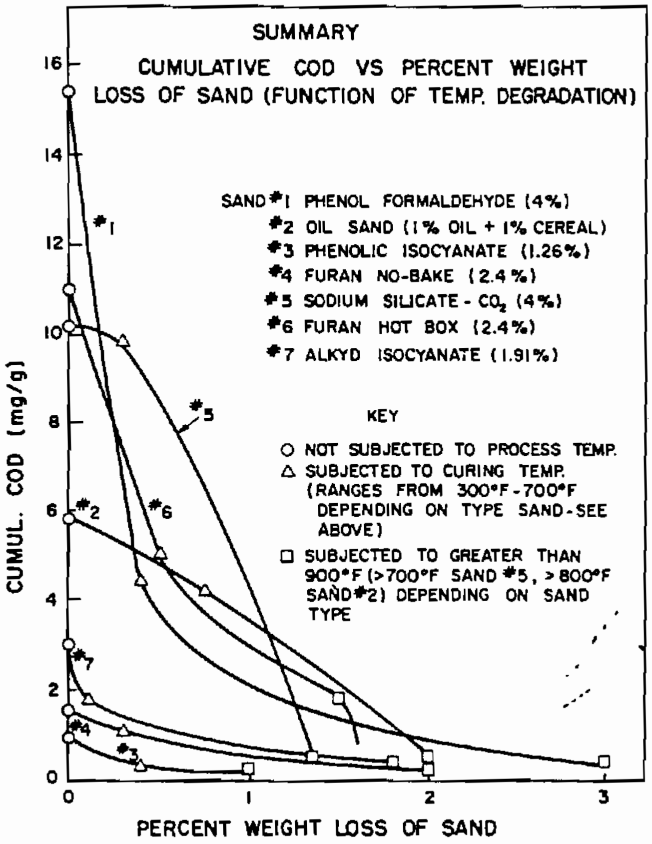
The importance of sand temperature degradation to matter release is summarized in Fig. 43 which presents curves of cumulative COD vs percent weight loss of sand. These curves indicate for sands 1-7 that cumulative release of COD in shake flasks decreases as the temperature to which the sands have been subjected increases. In other words, the less binder, the less COD is released. Temperature levels are represented in these curves by percent weight loss or volatilization during high temperature degradation prior to leaching.

Column Test

During initial development of the laboratory testing procedure, a relatively simple column test was conducted on a sample of molding sand. A 1-in.-diameter glass tube was packed with approximately 4 in. of molding sand which had been contacted with molten metal. No attempt was made to tamp or compact sand in the tube. Water was poured into the tube in a quantity that provided about a 4-in. head over the sand. After several minutes, water infiltrated about 1 to 1-1/2 in. into the sand column but moved no further. The column was allowed to stand for three days, after which no further infiltration was found.

Although this test was used as a rapid and simple examination of the use of columns in a standardized testing procedure and permeability was not measured, it did show the ability of molding sand containing 6% western bentonite and 7% seacoal to retard the downward movement of water.

Based on a review of research by Santa Maria[5] a large portion of foundry sand waste deposited in a land disposal site (generally 70% or more) consists of molding sand. This may have an effect on water infiltration through a foundry waste site.



(FROM "SAND TEMPERATURE DEGRADATION CURVES"-FOUNDRY WASTE MATERIALS TO LANDFILL, C. SANTA MARIA)

Fig. 43. Summary of cumulative COD vs percent weight loss of sand.

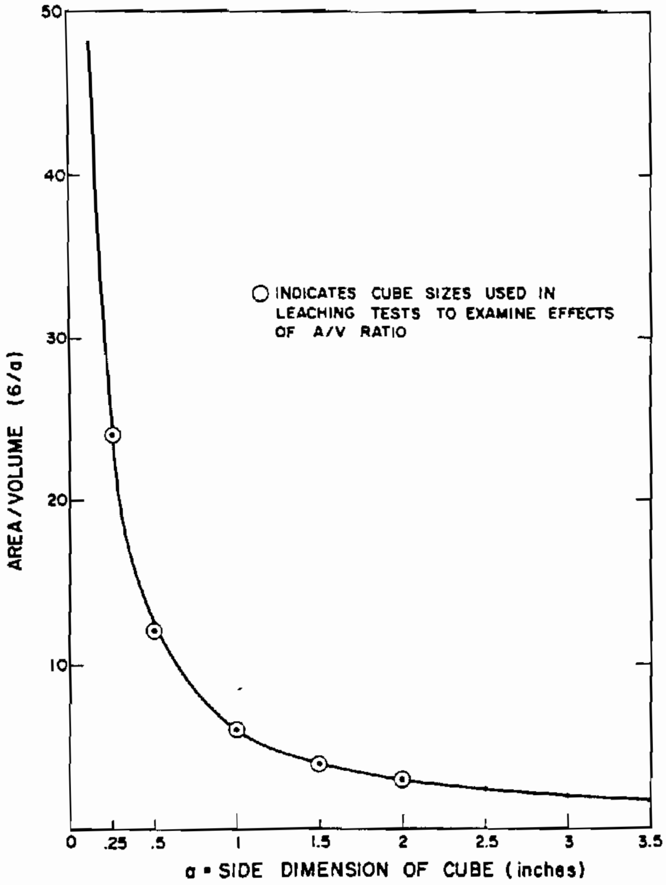
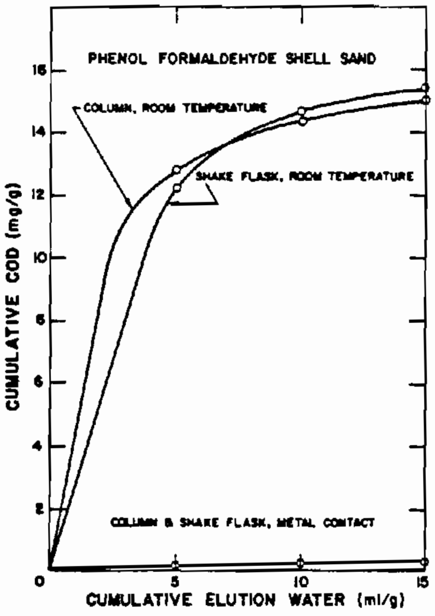


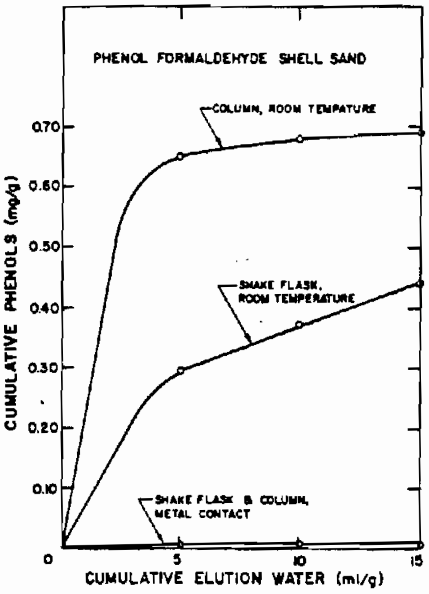
Fig. 44. Area/volume ratio for cube side of dimension "a."

Column Analyses

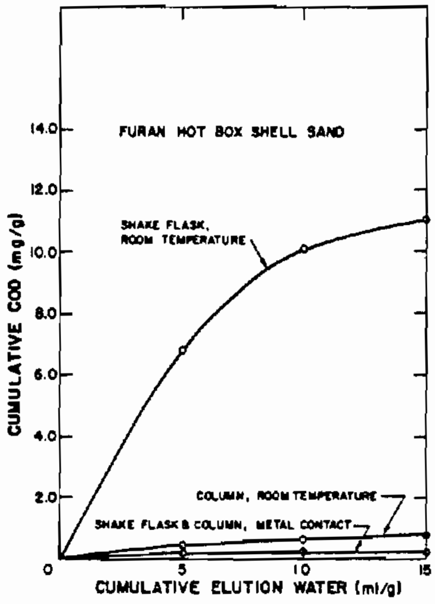
As an ancillary portion of the laboratory research studies on foundry sands, permeability tests were performed on a selected number of sands. These tests were performed in accordance with ASTM D2434-68 (1968) employing a 3.5-in. acrylic cylinder. To prevent short-circuiting of water along the sides of the column, a thin layer of clean silica sand was glued to the inside of the column. During the test period, samples were collected for leachate analysis. Comparisons were made directly with batch shake-flask tests. Results of several selected tests are illustrated below (a-f). It is apparent that no clear relationship exists between batch and column test procedures. In some cases the column and shake-flask results agree, whereas in others only order-of-magnitude agreement was reached. (Both procedures did, however, respond in similar manner to different treatments of the sands.) Since leaching mechanisms are different for the batch and continuous-flow conditions, it is not unreasonable to expect different results in these two procedures. Since batch techniques are normally easier to conduct and are more reproducible, they would normally be the method of choice in a cursory test of this type.



(a)



(b)



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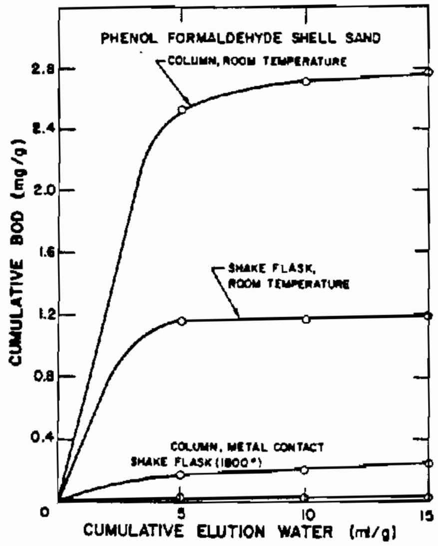

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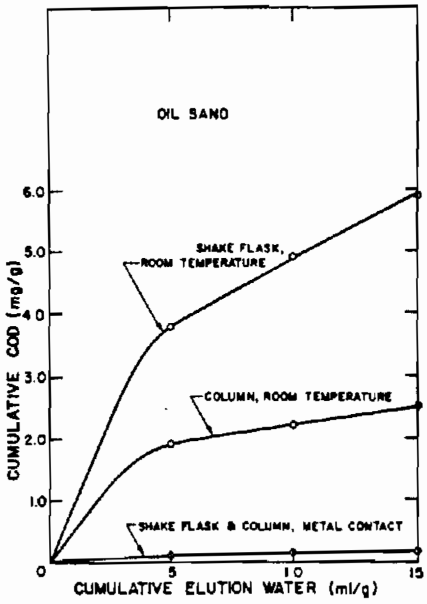

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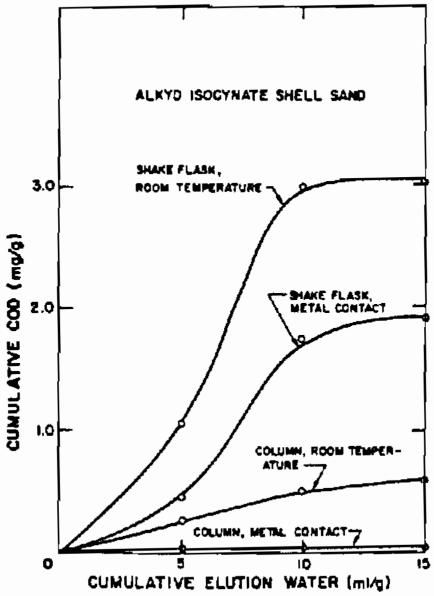


(f)

Leaching Effects of Sand Core Cube (Butt) Size or Area/Volume Ratio

Limited tests were conducted to examine the effects of sand core cube size or area-to-volume ratio on leaching characteristics. These tests were based on preliminary indications during early phases of standardized test procedure development that larger pellets (approx. 1 cm long) made up of many bonded individual sand particles exhibited approximately 1/3 - 1/2 less matter release (mg/g) than did individual sand particles. To examine this condition in more detail, a series of tests was run on cured (400-500F (204-260C)) phenol-formaldehyde shell sand that had been prepared in several core cube sizes and area-to-volume ratios. First, a curve (Fig. 44) was constructed representing area-to-volume ratio as a function of core cube dimensions. Samples in the shape of cubes and in sizes corresponding to several points on the curve were then prepared in a uniform manner under controlled conditions. Preliminary testing was necessary to set forth preparation and curing requirements of cubes prior to leaching.

Figure 44 shows that area-to-volume ratios increase substantially as core sube size decreases below 1 in. per side. However, for lateral dimensions greater than 1 in., area-to-volume ratio does not change appreciably. Tests previously conducted on the eight sand types involved sand aggregates prepared to a 20-mesh size. This size particle has a comparatively high area-to-volume ratio, beyond any values shown in Fig. 44.

To evaluate area-to-volume ratio effect, test procedures involved two sand-water contact mixing methods — shake-tests as conducted in the previous work and stir tests which involved a paddle-type stirring mechanism rather than the reciprocating shaker. The stirring mechanism used was a Phipps and Bird laboratory stirrer with 3-in.-long paddles and speed which is variable from 0 to approximately 300 rpm. A speed of 100 rpm was used. Intermittent stirring, applied with the same frequency as shaking, was used for the purpose of decreasing the opportunity for sand cube attrition due to dynamics of shaking. During the tests, core cubes contained in 2-qt mason jars did not break down but remained intact.

This relationship may have important implications in land disposal situations since much of the core sand material delivered to a landfill is in the form of core butts, many of which appear much larger than 1-in. cubes. This means that for the number of individual sand particles present in core butts, the total surface area readily available for contact with water is substantially less than if the material were delivered in a crushed condition.

Figures 45-48 present COD and phenol release from cured shell sand as a function of core cube size. COD release for cubes using the shake method is estimated (Fig. 45) for the first sampling period due to analytical problems. The release range shown is felt to be a reasonable estimate. It is based on preliminary testing on cubes that were not prepared in a uniform manner plus results from the stir method tests.

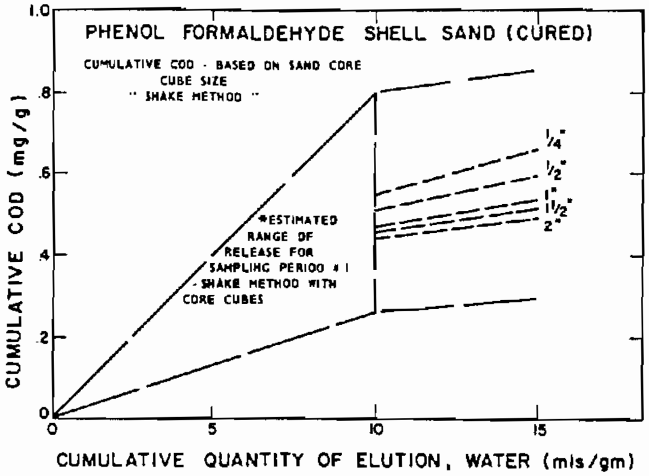


Fig. 45. Cumulative COD based on sand core cube size, shake method.

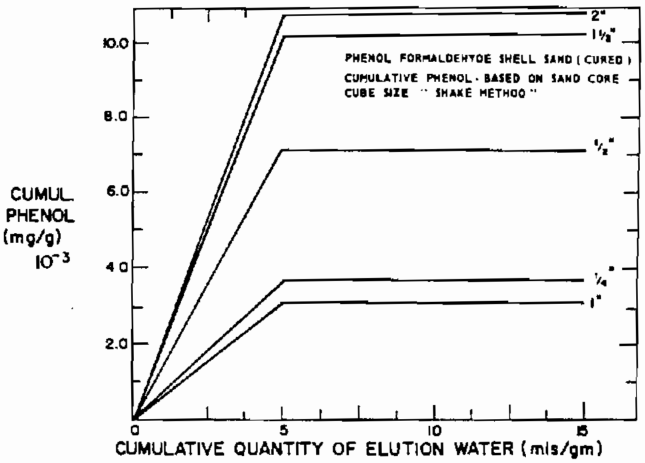


Fig. 46. Cumulative phenol based on sand core cube size, shake method.

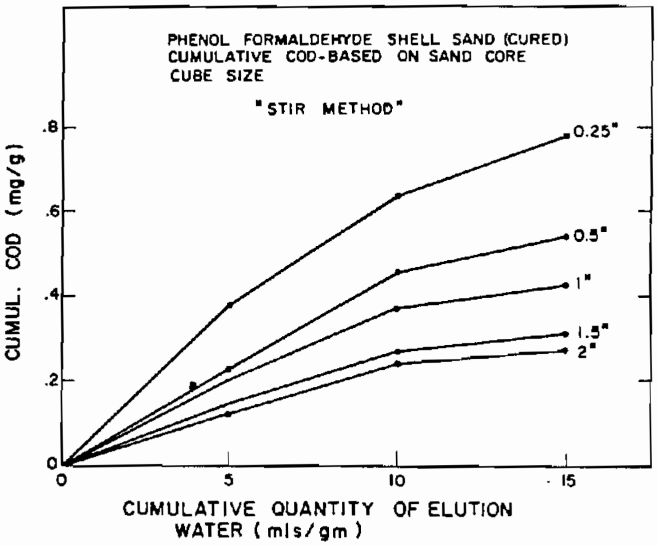


Fig. 47. Cumulative COD based on sand core cube size, stir method.

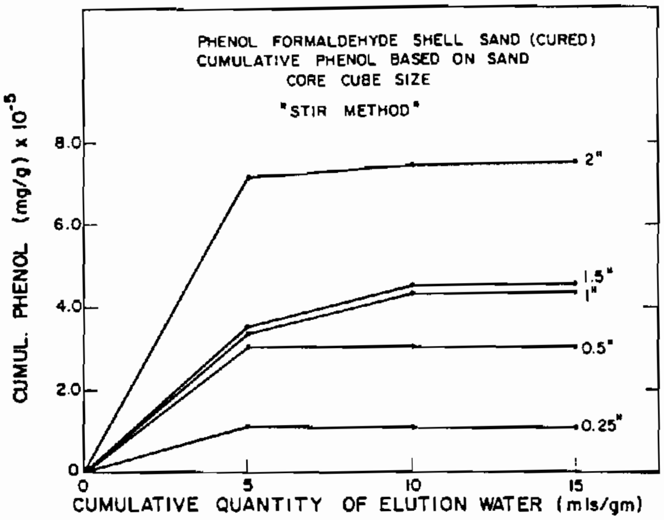


Fig. 48. Cumulative phenol based on sand core cube size, stir method.

The data indicates a direct correlation between core cube or butt size (area/volume ratio) and release which was detected. The smallest cube (largest area/volume ratio) exhibited the greatest cumulative release of COD, whereas the largest cube (smallest area/volume ratio) exhibited the least cumulative release of COD. At the end of the third sampling period approximately three times the cumulative COD (mg/g) was obtained from the 1/4-in. cube as from the 2-in. cube. The relationship held true for both the stirring and shaking methods of mixing but adequate release analyses from the shake tests were obtained only from sampling periods 2 and 3.

Release curves (COD) from core cubes tested in this sequence of tests generally assumed the same basic shape as the release curves for small sand aggregate size. Release was relatively high during the first sampling period and continued cumulatively at a decreasing rate in the second and third periods. However, at the end of the third sampling period, cumulative release from all core cubes (1/4 to 2 in.) was not as high as release from the small particles tested in the earlier work. For sands subjected to curing temperatures, COD release from cubes was 1/5 or less than that released from small sand particles. Values were of the same magnitude, however, for sand which had been subjected to temperatures greater than 1800F (982C).

The most significant finding in regard to phenol for this test was the extremely low release as compared to that found for small sand particles. Phenol release for cubes ranged from 1 to 4 orders of magnitude less than phenol release for sand particles subjected to the same curing temperatures. Release levels for cubes were below those detected for 20-mesh particles for sands subjected to pouring temperatures (2700F (1482C)). The low levels of phenol release are near the low end of phenol detection limits for the analytical techniques used. Figure 48 shows that phenol release from cubes performed differently than COD release. Larger cubes released higher levels of phenol on a per-gram basis than did the smaller cubes, even though the differences were small. This may be due to dynamics of the mixing process. Mixing of water and larger cubes may result in greater sand attrition than would occur with smaller cubes.

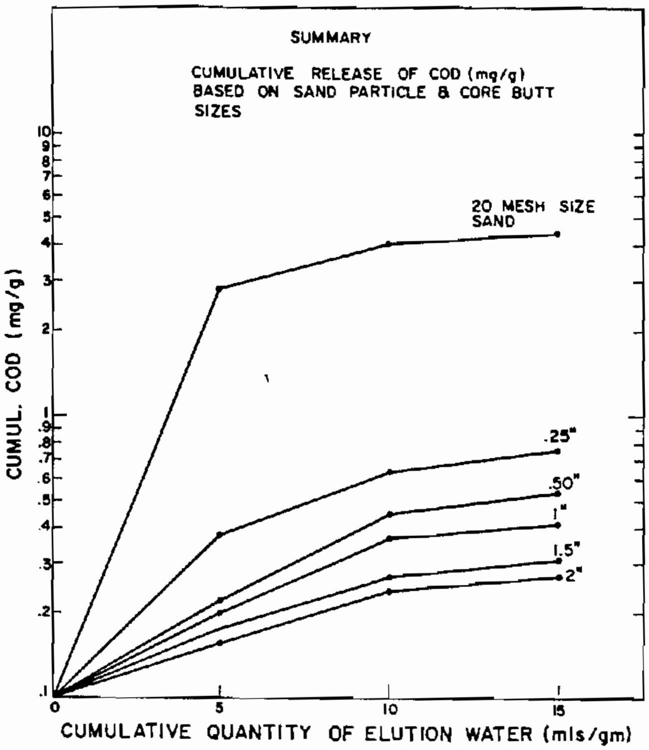


Fig. 49. Summary — cumulative release of COD based on sand particle and core butt sizes (sand subjected to curing temperature).

Comparisons of COD and phenol release for 20-mesh particles and for various cube (butt) sizes are summarized in Fig. 49 and 50. Figure 49 presents a comparison of COD release from 20-mesh-size sand subjected to curing temperature (from Fig. 8) with corresponding release from core cubes (from Fig. 47). Figure 50 presents a comparison of phenol release from 20-mesh-size sand subjected to curing temperature (from Fig. 12) with equivalent release from core cubes (from Fig. 46 and 48).

It appears that use of small sand particles in the standardized test procedure is likely to provide maximum matter release within a relatively short and predictable period of time.

Of practical significance, these results also suggest the potential importance of core butt sizes actually taken to the landfill site in evaluating in-field leaching characteristics. Further examination of the area/volume ratio-leaching character relationship is recommended.

Molding Sand — Shell Sand Combination

Throughout the entire leaching studies, all sands were examined individually to determine maximum laboratory leaching characteristics. However, in actual landfill situations, sand materials are usually combined and are delivered to the site in a mixed form. The proportions of various sands taken to sites depend on the processes involved in each foundry operation.

To examine, in a preliminary way, what effects combining waste sands may have on laboratory leaching results, a series of tests was conducted on a combination of molding sand and shell sand. Materials balance studies for seven different foundries indicated that a combination

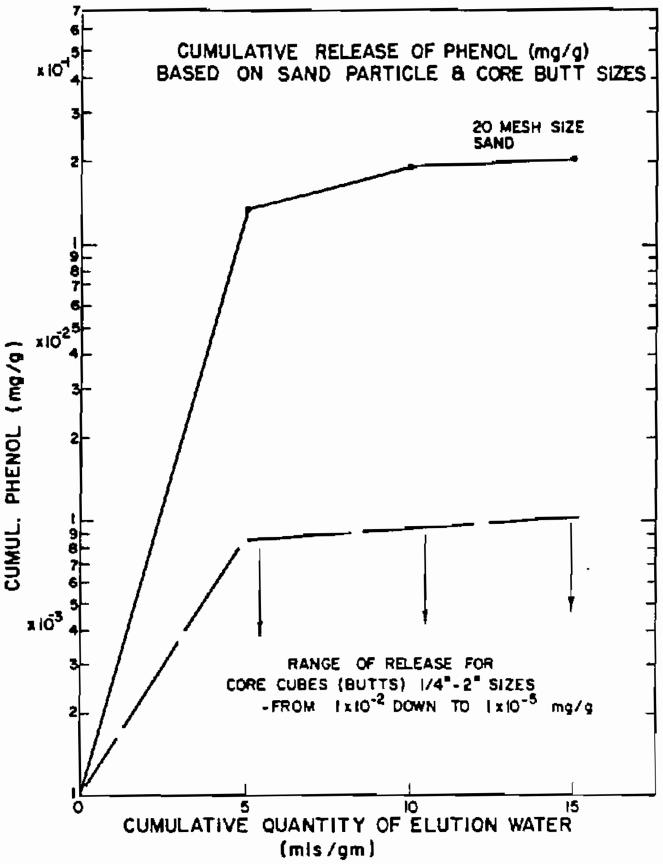


Fig. 50. Cumulative release of phenol based on sand particle and core butt sizes (sand subjected to curing temperature).

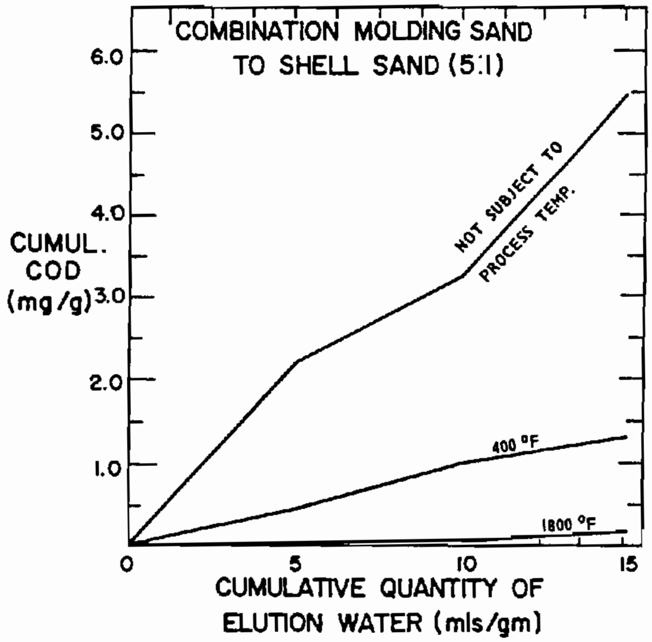


Fig. 51. Combination of molding sand to shell sand (5:1), cumulative BOD vs cumulative quantity of elution water.

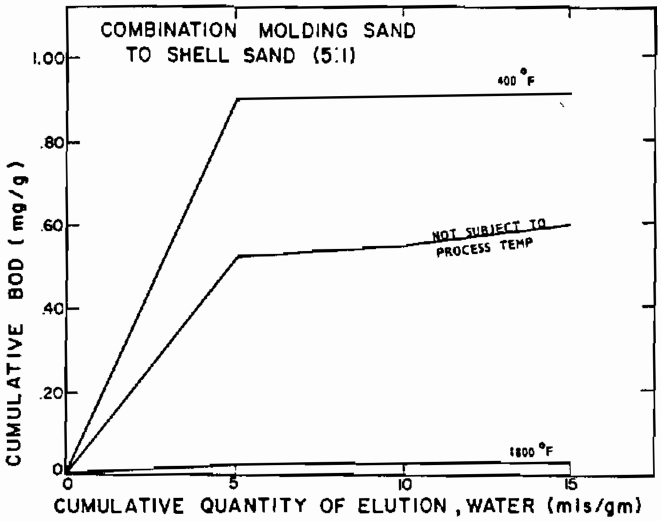


Fig. 52. Combination of molding sand to shell sand (5:1), cumulative BOD vs cumulative quantity of elution water.

of five parts molding sand to one part shell sand would provide a sample that is broadly representative of actual sand ratios which might be found in a landfill. Calculations based on release values for individual sands were made to compare predicted and measured values of release from the shell sand-molding sand combination. Results of laboratory leaching tests on the combined sand samples are given in Fig. 51-53.

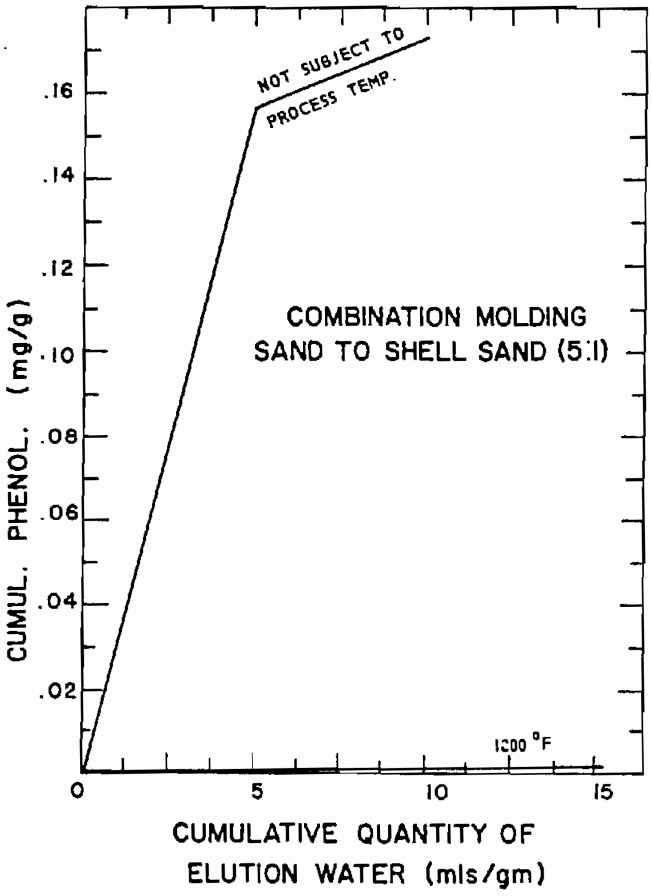


Fig. 53. Combination of molding sand to shell sand (5:1), cumulative phenol vs cumulative quantity of elution water.

Table 15. Comparison of Predicted and Actual Release Values for Sand Combination

	COD (mg/g) Calculated Values	(Actual Values)	BOD	Phenol
Sand not subjected to process temperatures	3.6	(5.5)	1.0 (0.6)	0.1 (0.2)
400F	2.0	(1.3)	0.8 (0.9)	
1800F	0.7	(0.2)	0.2 (0.0)	0.0 (0.0)

The effect of process temperature on release is generally maintained in these results. Release was highest from sand not subjected to process temperature, except for BOD of the sand subjected to approximately 400F (204C).

Release levels reflect quite well the proportional mix of molding sand and shell sand. On the basis of milligrams of release per gram of sand combination, release is less than release from shell sand only but is more than release from molding sand only. A comparison of calculated, predicted release values with actual values is given in Table 15.

These results indicated predictive capability to be fairly reliable for calculating matter release from sand combinations based on use of release data from individual sands. However, in column studies and landfill situations, this relationship may differ due to differences in material, permeabilities, saturation, moisture routing, clay swelling, etc. Hence, release results presented here should be considered characteristic only of laboratory shake-flask tests.

Use of Batch Testing Procedures

It is apparent from the preceding discussion that batch testing procedures will provide the profession with useful data in evaluating a foundry's solid waste disposal situation. Analyses of individual solid waste components will provide information on important sources of potential pollutants within the foundry and will give a quantitative estimate of relative contributions of these pollutants.

Table 15A. Total Release of COD and Phenol by Shake-Flask Tests (Foundry IV)

Component	Release Values COD-mg/g	Phenol-μg/g
System sand	0.84	0.003
Core butts (2 x 2-in. pieces)	0.19	0.038
Coreroom sweepings	3.1	0.186
Slag and coke ash	0.99	0.28
Dust collector discharge	0.69	1.91
Scrubber discharge	0.42	0.48

The data provided by batch leachate analysis of individual components may be used to develop a composite leachate contribution for a given foundry. An example of this is provided for a gray and ductile iron foundry (foundry IV), as presented Tables 15 A and 15B. Batch tests for six components within the total waste were performed in accordance with the batch test procedure and are presented in Table 15A for COD and phenol. Using the percent contributions of each of the components to the total waste in foundry IV, estimated maximum leachate pollutant values for the foundry can be calculated (Table 15B).

Since mixing of components within the foundry may have a synergistic or antagonistic effect upon leaching of a particular substance from the waste, a comparison was made between the component analysis, using the calculations described above, and a batch analysis of a sample of the mixed waste. Results of this comparison for four foundries (I, II, IV and VII) for both COD and phenol are shown in Table 15C.

It is recognized that sampling of mixed wastes is highly complex and errors in obtaining representative samples are great. Yet comparisons for COD are reasonable and, as might be expected, COD values are somewhat lower for estimates using mixed wastes, possibly owing to adsorption of pollutants on clay materials. However, comparisons for phenols are poor, the mixed waste producing values one order of magnitude higher. It is not clear whether sampling of mixed waste resulted in substantial destruction of core butts, thereby producing significantly higher releases than would be expected, or whether other components within the waste resulted in a more favorable release of phenol.

Table 15B. Estimation of Release of COD and Phenol from Foundry IV with Shake-Flask Data

Components	w/w(%)	Shake Flask COD (mg/gm)	COD Mixture (mg/gm)	Shake Flask Phenol (μg/gm)	Phenol Mixture (μg/gm)
System sand	51.83	0.84	0.4354	0.003	0.0016
Core butts	10.11	0.19	0.0192	0.038	0.0038
Coreroom sweeping	3.67	3.1	0.1138	0.186	0.0068
Slag	20.83	0.99	0.2062	0.28	0.058
Dust collector discharge	9.84	0.69	0.0679	1.91	0.188
Scrubber discharge	2.12	0.42	0.0089	0.48	0.0102
Refractories	1.09	0.0	0.0	0.0	0.0
Cleaning room waste	0.51	0.0	0.0	0.0	0.0
TOTAL	100.0%		0.85 mg/gm		0.27 μg/gm

Table 15C. Comparisons of Shake-Flask Release for Component vs Mix Preparation

Foundry	Component Analysis*		Mix Analysis**	
	COD-mg/g	Phenol-µg/g	COD-mg/g	Phenol-µg/g
I	0.408	0.053	0.4	0.80
II	0.218	0.026	0.2	0.16
IV	0.853	0.268	0.4	6.12
VII	0.828	0.052	0.8	1.71

Comments

1) Results reported here are of a laboratory nature. They should not be interpreted as absolute values for what would occur in a fill site.

2) Stress on sand in laboratory tests is expected to be more severe than would occur in a fill site, particularly due to laboratory pulverization of cores and sand, continuous laboratory sand-water contact and the effect of distilled water.

3) Foundry solid wastes are generally deposited in land disposal sites in mixed condition consisting primarily of different types of sands that have been subjected to a variety of foundry temperatures and processes. Most sand actually taken to a landfill site will have been subjected to process temperatures. In general, highest laboratory release was found from sand not subject to process temperatures.

Conclusions

Standardized Test Procedure

1) The shake-flask technique developed in this project is a relatively rapid and simple method that can be used to obtain apparent maximum release of matter from foundry sand under conditions of continuous sand-water contact.

2) The test method yields reproducible results.

3) Proper sample selection and preparation are essential to obtain representative and reproducible test results.

Results from Standardized Test Procedure

1) The level of process temperature to which sand is subjected in the foundry has a major effect on leaching potential. Sands not subjected to process temperatures generally showed the greatest matter release.

2) Differences in release of matter were obtained for different sands. This reflects differences in both quality and quantity of resins and binders present in the sands.

3) The amount of molding sand containing clay and its distribution throughout a landfill, is likely to have significant effects on fill permeability and leachate quantity and movement.

4) The size of core butts taken to the landfill is likely to have a significant effect on leaching potential. Core butts generally released at approximately the same levels as thermally degraded molding sand.

5) Matter release from combinations of foundry sands can be predicted, based on calculations made using release data from individual sands.

6) Based on results which show differences in leaching among various sands, it is concluded that for foundry waste management and evaluation of leaching potential, it is important to obtain information regarding:

- Total amounts and types of wastes produced
- Types and amounts of resins and additives used
- Process area within the foundry producing wastes, amounts produced from each and process temperatures to which wastes have been subjected.

Such information might be obtained through a materials balance approach such as that presented in chapter one of this report, based upon the work of Santa Maria.

3

Development of Standardized Laboratory Testing Procedure

A series of six experimental runs or phases was performed to develop the standardized testing procedure. Each phase involved setting up experiments to meet specific objectives and was usually influenced by previous laboratory results. For this reason, phases will be presented and discussed in the order performed.

Development of Testing Procedure — First Phase Tests

Initial shake-flask tests were conducted to develop a laboratory testing procedure for the majority of the research.

Eight 500-ml erlenmeyer flasks were used for the first set (series A) of samples. Since it was felt that development of a standardized test procedure could best be accomplished by the use of a relatively uncomplicated foundry sand material, shell sand containing approximately 96% silica sand plus 4% phenol-formaldehyde resin binder was selected as test material. Prior to use in flasks, the sand was heated to a range of 400-500F (204-260C) to form the resin bond. It was then allowed to cool and was pulverized into a mixture of sand and small pellets.

To determine the effect of sample and particle size on release of matter from the sand, sample quantities varied from 10 to 100 g and particle sizes varied from oblong pellets approximately 1 cm in length to fine and very fine sand. The effect on matter solubility of the ratio of sand sample size to quantity of shake water was examined by using distilled water in volumes that varied from 300 to 500 ml. A flask containing only distilled water was used as a blank, or standard, on which to determine release of matter attributed to foundry sand material. Series A flasks consisted of the following sand and water contents:

A1 — 10-g pellets with 300 ml distilled water
A2 — 50-g pellets with 300 ml distilled water
A3 — 50-g sand with 300 ml distilled water
A4 — 100-g sand with 400 ml distilled water
A5 — 10-g sand with 300 ml distilled water
A6 — 100-g pellets with 500 ml distilled water
A7 — 50-g pellets with 500 ml distilled water
A8 — 50-g pellets with 500 ml distilled water

Flasks A1-A6 were shaken continuously on a reciprocating shaker. For comparison, flasks A7 and A8 were not shaken. Solution sample volumes of 200 ml were removed from each of the flasks and were replaced by 200 ml volumes of distilled water. This was done to more closely simulate a possible field condition of quantities of rainfall or groundwater passing through the foundry sand material, displacing equal and previously held quantities of water. Removal of solution samples and analysis were initially done at 2-day intervals and then at 3-day intervals. Solution samples were analyzed for alkalinity, nitrate-nitrite, COD, pH, conductivity, chloride and sulfate. Solution sample volumes of 50 ml were also withdrawn from all 200-ml samples and were analyzed for a variety of other constituents. Data from the majority of the analyses is given in Fig. 54-56.

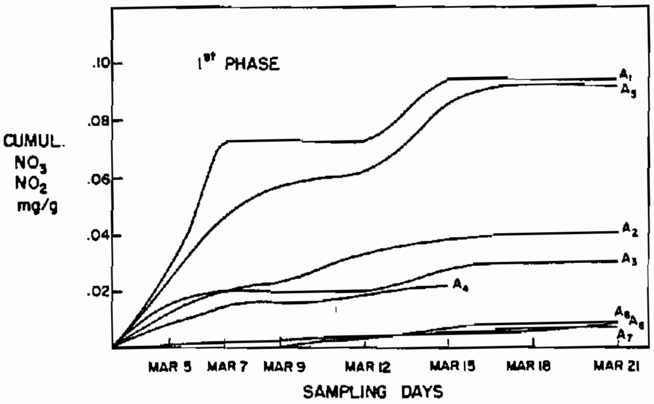


Fig. 54. 1st phase, cumulative NO_2-NO_3 vs sampling day.

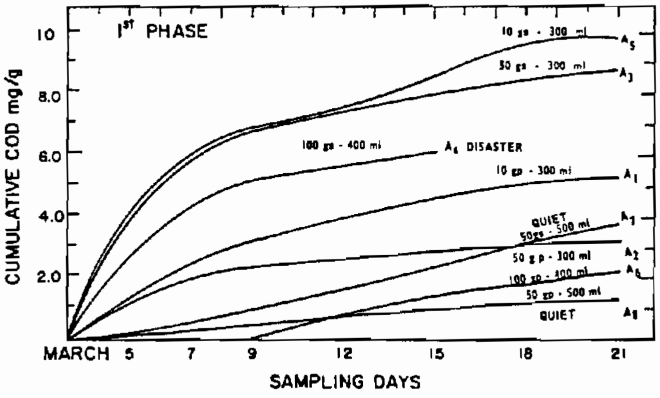


Fig. 55. 1st phase, cumulative COD vs sampling days.

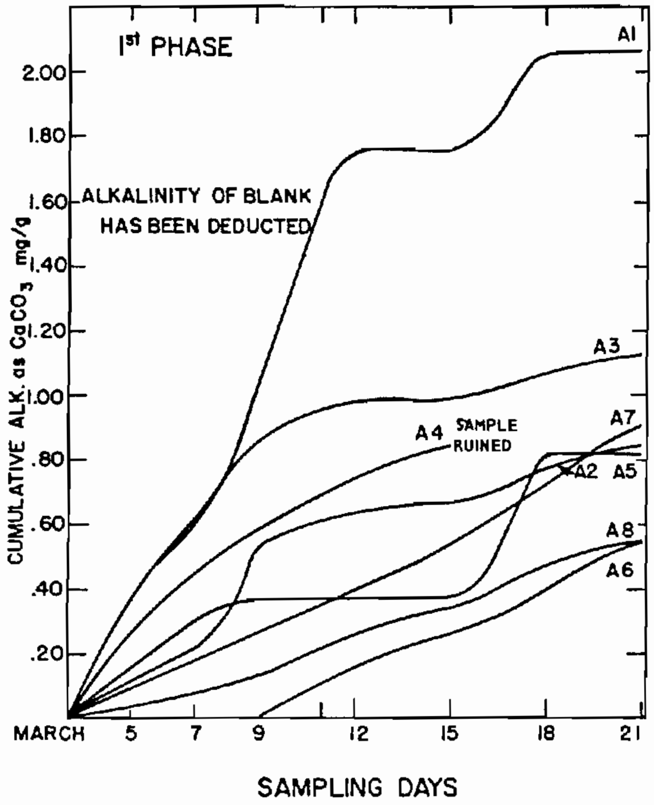


Fig. 56. 1st phase, cumulative alkalinity vs sampling days.

Analysis of the data indicates that COD release, in particular, was fairly high. This result certainly cannot be judged as an indicator of release that would occur under actual field disposal conditions, but it is an indication of the maximum cumulative release of matter under laboratory conditions.

It is observed that flasks containing the smallest ratios of sand sample size to water quantity yielded the greatest release of matter when adjusted to a per-gram basis. Hence, a strong indication was given that the test procedure of removing only 200 ml of flask water at each time of analysis may result in the limiting of matter solubility or saturation of the flask water. This could initially result in an unrealistically low release of matter from the sand samples and would tend to greatly lengthen sampling time required for the slope of the release curves to level off, indicating maximum release. Based on these findings, it was concluded that the test procedure used for series A samples was inadequate. The procedure was, therefore, abandoned after the seventh set of analyses.

Shaking showed a significant effect on release of matter. Samples that were shaken released higher initial quantities of matter than did unshaken samples. Examination of the release curves reveals that after approximately three sets of samplings and analyses, slopes of the curves for shaken samples tend to level off while slopes of the curves for unshaken samples tend to continue steadily rising. It is possible that after a long period of time, total release of matter may reach the same level for both shaken and unshaken samples. To facilitate analysis and plotting of cumulative release curves in the most reasonable time, shaking of samples was determined to be the more useful procedure.

Sand yielded an earlier and greater release of COD than did pellets. The effects of particle size on nitrate-nitrite and alkalinity were not readily discernible. At the time of the first solution analysis, pellets were observed to be reduced to sand by the shaking process. Pellets in the unshaken flask remained in pellet form throughout the series A tests.

Since all pellets in the shake flasks were reduced to sand after a short period of shaking and since the previously unpelletized sand continued to release cumulatively greater quantities of COD than did the reduced pellets, it was speculated that mechanical pulverization of sand prior to use in the flask tests may cause excessive separation or abrasion of the resin coating from the individual sand particles, resulting in higher COD release. At the conclusions of series A tests, examination of the slopes of the cumulative release curves did not show evidence that over a much longer time period, the cumulative release of COD will approach the same quantities for comparable sand-water and pellet-water mixtures.

Development of Testing Procedure — Second Phase Tests

The second phase of testing included use of an alternate method for withdrawing solution samples and adding fresh distilled water, comparison of results and plotted release curves with the results and curves of initial tests and determination of the effect on matter release of mechanical pulverization of sand samples.

To provide testing continuity from the first to the second phase, sand samples for this phase were taken from the same sand quantity which supplied samples for the initial phase. Because sand is more homogeneous, easier to work with and generally provides more rapid matter release than pellets, it was used exclusively in this phase. In addition to a blank flask containing only 400 ml of distilled water, six flasks were used for this set of samples (series B). Three flasks were prepared as replicates of three of the flasks run in the initial phase. The remaining three flasks were prepared with larger quantities of both sand and distilled water. This was done to provide sufficient volumes of solution for analysis in three parts. Series B flasks were prepared in the following manner:

B1 — 200 g sand with 800 ml distilled water in 2-liter flask
B2 — same as B1
B3 — same as B1
B4 — 100 g sand with 400 ml distilled water in 500-ml flask
B5 — 50 g sand with 300 ml distilled water in 500-ml flask
B6 — 10 g sand with 300 ml distilled water in 500-ml flask
Blank — 400 ml distilled water in 500-ml flask.

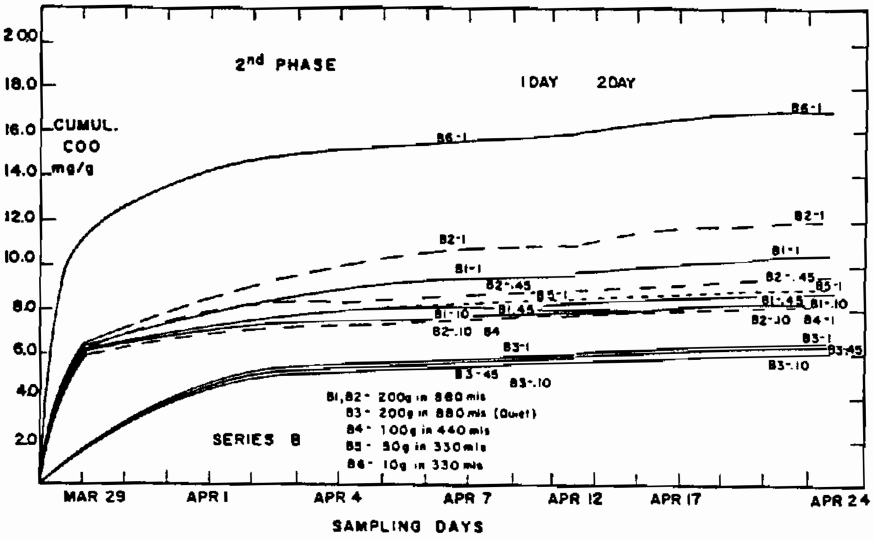


Fig. 57. 2nd phase, cumulative COD vs sampling days.

All flasks, with the exception of B3, were continuously shaken on the reciprocating shaker. Flask B3 was not shaken. To direct this sampling procedure at the solubility limiting problems and long-term sampling requirements experienced in the initial testing phase, each time a sample of solution was withdrawn, the entire quantity of solution was removed from the flask. After being taken off the shaker and without being allowed to settle, the contents of each flask were placed on a Whatman #1 filter and the liquid allowed to filter through. The sand was rinsed with distilled water, 10 ml per 100 ml of filtrate. The rinse water was combined with the filtrate. The sand was returned to the flask, being rinsed from the filter paper and distilled water was added to return it to the original volume. Shaking of the sand and fresh water was then resumed.

To determine the effects of sand pulverization on matter release, each of the three 800-ml solution samples was divided into three parts and analyzed. One fraction (400 ml plus 40 ml rinse water) was analyzed after only rough filtering through the filter. The remaining 400 ml plus 40 ml rinse water was passed through a 0.45-micron filter after which half that quantity (220 ml) was analyzed. The remaining 220 ml was passed through a 0.10-micron filter and then analyzed. The filtering and analysis of solution sample fractions were done in an attempt to detect the abrasion of minute particles of resins coating during sand pulverization. If significant differences were observed in the levels of matter release when comparing the samples passed through three sizes of filters, it could be considered an indication that abrasion does significantly affect the level of matter release and that continued filtering should become an essential part of the testing procedure. In addition to detecting an increase in released matter due to mechanical sand pulverization, the filtering technique attempted to detect an increase due to abrasion during the sand-water shaking process. In either case it did not seem necessary to determine the source of abrasion but simply to detect its presence and its effect on matter release and then to compensate for it through the use of filtering techniques.

During this phase, the first set of analyses was completed the day after the flasks were prepared. Subsequently, sampling and analyses were done at 3-day intervals, followed by 5-day intervals and then at 7-day intervals. Less frequent sampling and analyses were felt to be appropriate since the levels of matter release generally dropped significantly after the first day. Analysis included the same materials in this phase that were included in the initial phase.

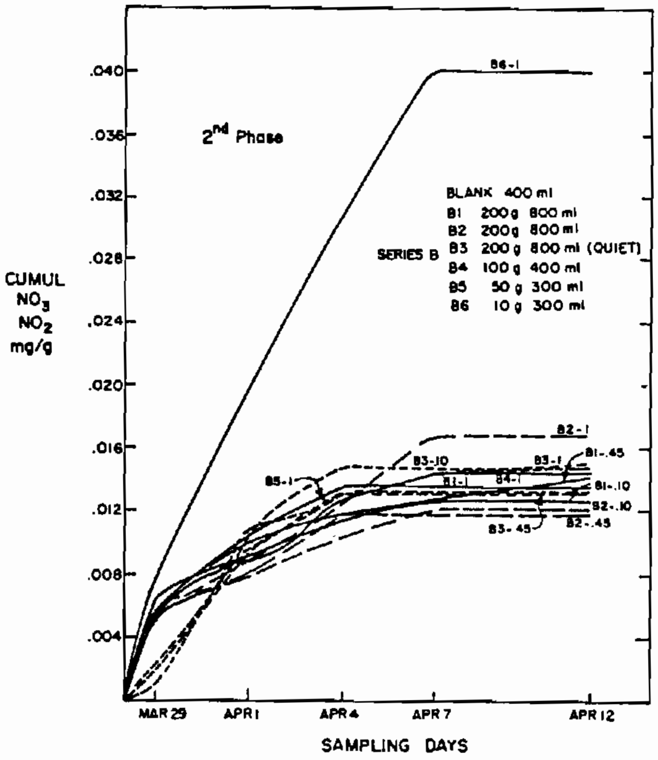


Fig. 58. 2nd phase cumulative NO_2-NO_3 vs sampling days.

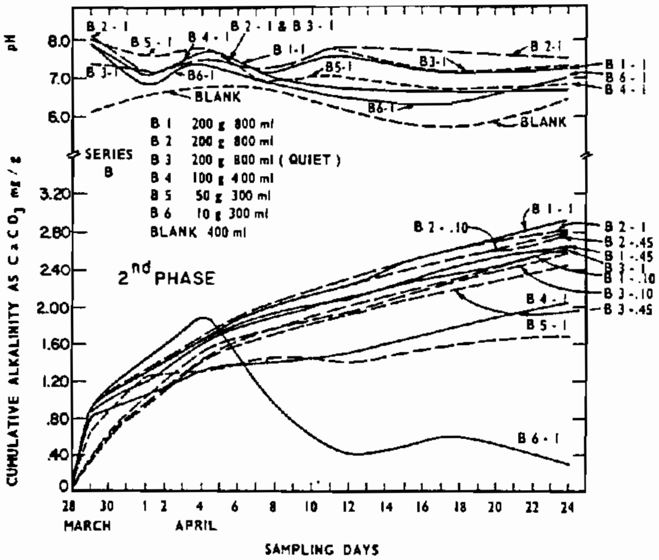


Fig. 59. 2nd phase, cumulative pH and alkalinity vs sampling days.

The data is plotted in Fig. 57-59. On a per-gram basis, the sample containing the smallest ratio of sand quantity to water volume released higher levels of matter. This may indicate the use of a bad or unrepresentative sample. It was determined that additional samples should be run to examine this possibility and to attempt to achieve reproducible results. Some method of sand mixing and fractionating might be used to ensure a fairly random and representative selection of sand.

Differences in the detection of matter release at various filter levels indicate some abrasion of minute particles through either the grinding process for preparing sand samples or through the water-sand shaking process. However, the effect of the abrasion on release appears to be minimized by filtering to the 0.10-micron filter level.

At the conclusion of this testing phase, questions were raised concerning the possible solubility of silica and its effect on COD as well as the effect of sampling frequency on test results. Additional tests were run to evaluate these factors.

Development of Testing Procedure — Third Phase Tests

Major features of the third phase of testing to develop standardized laboratory procedures included use of a splitting technique for selecting representative sand samples, examination of the effect of sand-to-water ratios in the test samples, use of a pure silica-water sample to examine possible effects of silica on matter release and examination of possible effects due to sampling frequency. With the exception of these features, the testing procedure used in this phase was the same as that used in the second phase.

To select representative samples of sand for testing, a two-way splitter was used. The sand (96% silica plus phenol-formaldehyde resin binder) in total quantity of approximately 10 lb was poured through the splitter and initially divided into halves. Half the sand was then poured again through the splitter to divide it into halves.

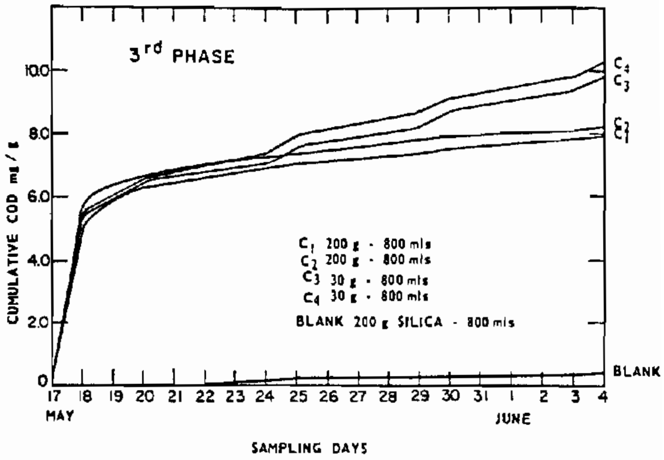


Fig. 60. 3rd phase, cumulative COD vs sampling days.

Again, one of the remaining halves was poured through the splitter for further division. This technique was continued until one of the remaining halves contained an amount of sand equal to or slightly greater than the amount needed for a test sample. The sample was then selected from this quantity of sand and adjusted to the desired weight. The splitting procedure was used independently for selecting each sand sample, even when replicate samples were prepared.

To examine the effect of sand-to-water ratios in test samples, replicate samples containing 200 g of sand in 800 ml of distilled water and replicate samples containing 30 g of sand in 800 ml of distilled water were used. Two-liter flasks were used for sample shaking on the reciprocating shaker.

A fifth sample was also prepared containing 50 g of hexane-washed silica in 400 ml of distilled water. This sample was used in an examination of the effect of silica on total matter release. However, since foundries typically do not operate with the use of hexane-washed silica, this sample was abandoned shortly after testing began and was replaced by a 200-g sample of Portage silica sand in 800 ml of distilled water.

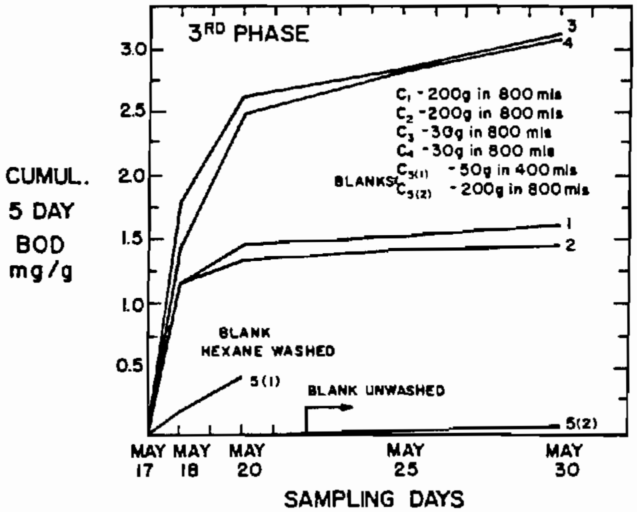


Fig. 61. 3rd phase, cumulative BOD vs sampling days.

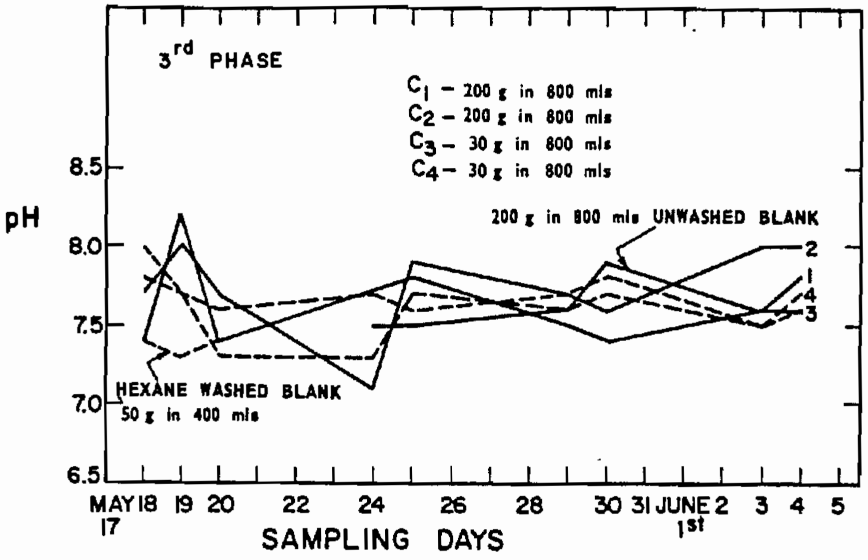


Fig. 62. 3rd phase, pH vs sampling days.

Finally, to examine effects of sampling frequency and number of elutions, samples were withdrawn and analyzed at the ends of the first, second and third days of shaking; at the ends of the seventh and eighth days; at the ends of the twelfth and thirteenth days; and at the ends of the seventeenth and eighteenth days. Each sample withdrawal signified a separate elution. Prior to analysis, each sample was filtered through a 0.10-micron filter. Analysis results are plotted on Fig. 60-67.

Reproducibility of test results is possible through use of the splitting technique for obtaining representative samples. Excellent reproducibility was obtained in the data for COD, BOD and solids when comparing within replicate samples. Reproducibility in results was not obtained when comparing replicates containing small sand-to-water ratios (30 g sand in 800 ml water) with duplicates containing large sand-to-water ratios (200 g sand in 800 ml water). It was concluded that this difference may be due to attrition of sand particles or resin resulting from the shaking procedure.

Frequency of sampling appeared to have minimal effect on release. The amount of matter released was similar regardless of which sampling frequency, among those tested, was used.

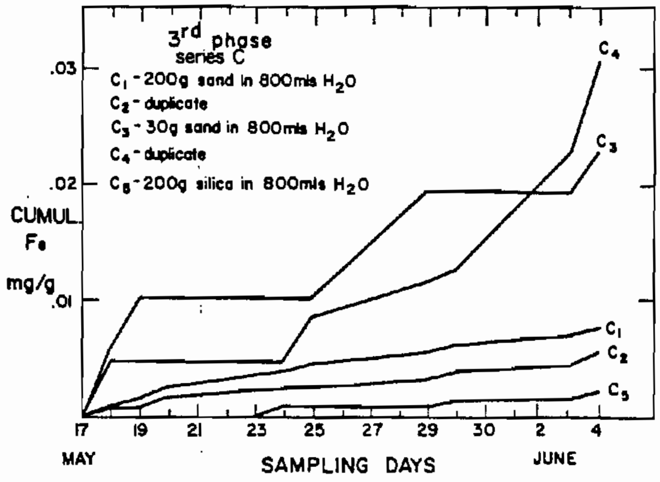


Fig. 64. 3rd phase, cumulative Fe vs sampling days.

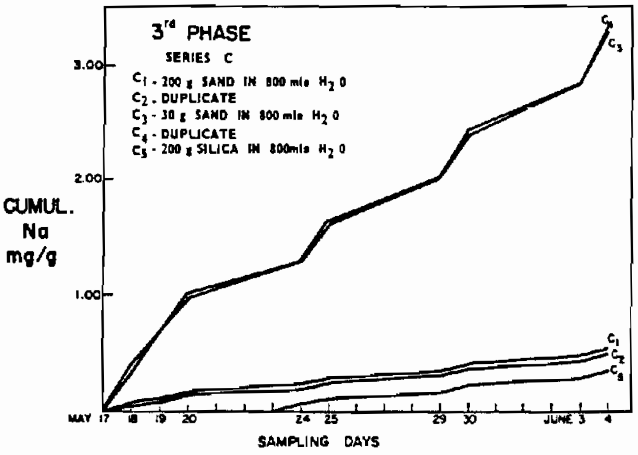


Fig. 63. 3rd phase, cumulative Na vs sampling days.

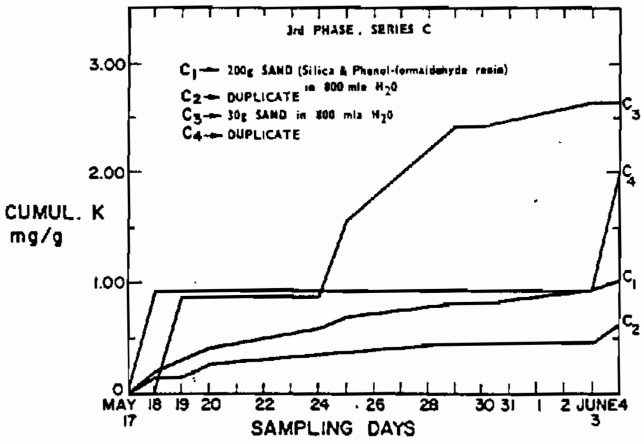


Fig. 65. 3rd phase, cumulative K vs sampling days.

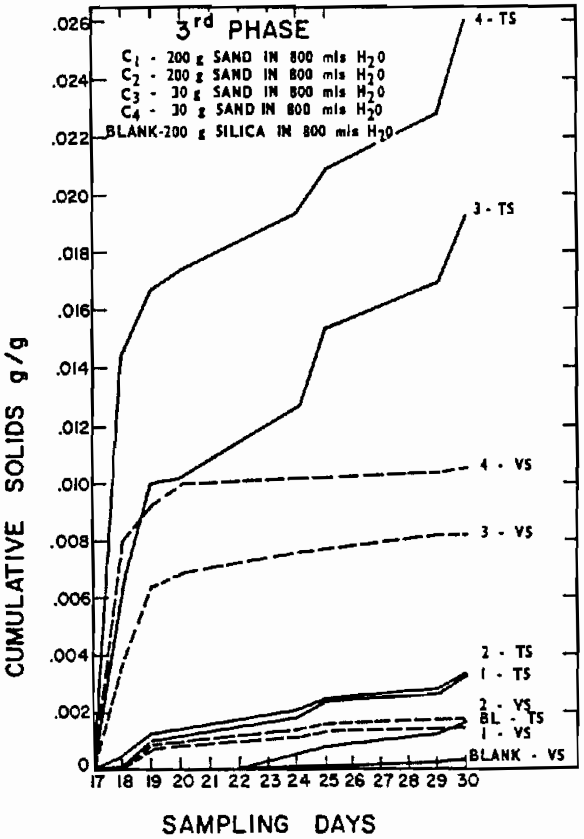


Fig. 66. 3rd phase, cumulative solids vs sampling days.

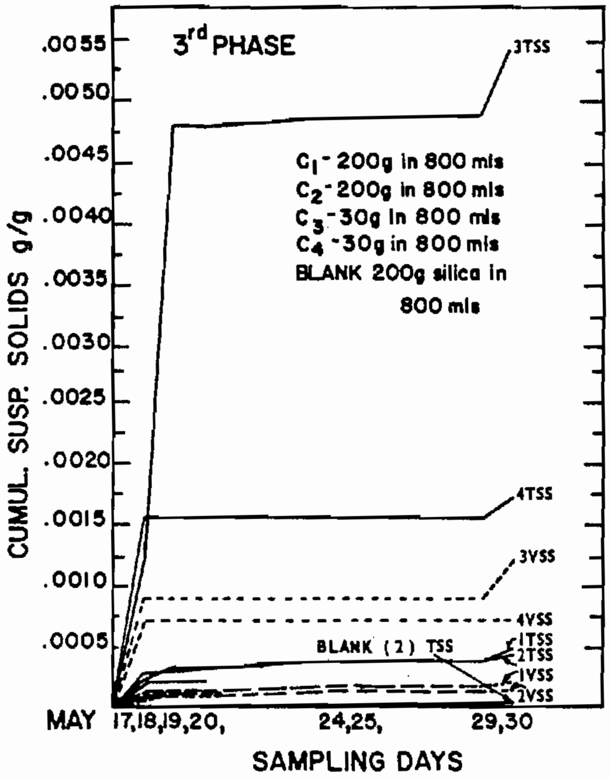


Fig. 67. 3rd phase, cumulative suspended solids vs sampling days.

Examination of the curves for cumulative release shows that, in general, the first two periods of shaking and sampling (first two elutions) are the most important. The greatest amount of release occurs during these periods. The third period of shaking and sampling (third elution) produces relatively less release, however, it is important in establishing the shape of the release curve.

Nearly all release curves indicate that after the fourth period of shaking and sampling or the fourth elution, release begins to increase and scatter in an unpredictable manner. It appears that this may be due to attrition of particles during the shaking process. While this scatter gives additional support for shaking and sampling and eluting only three times to plot release curves, further examination is necessary.

Differences in BOD levels between samples 1-2 and 3-4, as compared to COD levels between samples 1-2 and 3-4, can be attributed to toxicity threshold conditions. Phenol-formaldehyde is very toxic to microorganisms above threshold concentrations, which appears to cause the differences indicated on the curves. Pure silica produced insignificant amounts of COD, BOD and volatile solids.

At this point in developing a standardized test procedure, the major question remaining was that of nonreproducibility of results for samples with varying sand-to-water ratios. To further examine this problem, particularly with regard to possible particle attrition due to the shaking process, it was concluded that a less violent shaking technique should be developed and that a different type of sand should be examined.

Development of Testing Procedure — Fourth Phase Tests

Objectives of this phase of testing were to further examine matter release between samples with different sand-to-water ratios, to examine the effects of specific shaking procedures and to compare sample shaking-release relationships using a different sand material.

For this phase of testing, various parts of the procedure were changed. A facing sand containing silica plus 6% western bentonite and 7% seacoal was used. A portion of the facing sand (new sand) had been prepared without heat treatment while another portion (old sand) had been contacted four times with molten metal. Each portion was analyzed separately during testing.

A different shaking mechanism was also developed for this phase of testing. A flask holder was built so that samples could be rotated about an axis through the flasks rather than shaken. In addition, samples were rotated only twice per day for periods of approximately 15 sec each. This was done with the expectation that sand-water mixing could be accomplished with a minimum of particle attrition.

Since the sand tested in this phase contained 6% bentonite clay, it was felt that centrifuging of the sample would be necessary prior to filtering and analyzing. Samples used in this phase were prepared as follows:

Sand without heat treatment
  100 g in 800 ml water
  100 g in 800 ml
  30 g in 800 ml

Sand contacted with metal
  30 g in 800 ml
  30 g in 800 ml
  100 g in 800 ml

During the test runs, erlenmeyer flasks proved unworkable because of sand clogging in the necks during sample rotation. Use of wide-mouthed mason jars averted this problem.

Centrifuging was found to be necessary, because filtering just 200 ml of uncentrifuged sample took three days. It was determined that centrifuging must be done with high-speed centrifuge equipment.

Sticking and clogging of facing sand material was experienced when metal centrifuge tubes were used. Plastic tubes were much easier to work with.

Due to these flask and centrifugation problems, this test phase was abandoned after three days of sampling. No useful data was obtained.

In addition to the test described above, a crude column test was performed using facing sand material. The objective was to determine the practicality of using sand columns for predicting matter release from various foundry sand materials.

A one-in.-diameter glass tube was packed with approximately 4 in. of old facing sand (sand which had been contracted with metal). No attempt was made to tamp or compact the sand in the tube. Water, in a quantity that provided about a 4-in. head over the sand, was poured into the tube. After several minutes, water infiltrated about 1 to 1-1/2 in. into the sand column but moved no farther. The column was allowed to stand for three days after which no noticeable added infiltration was found.

This test indicated that the use of columns would probably be impractical for sand containing significant quantities of clay. For this reason, columns were not selected as the major means of testing. It was further concluded that good release comparisons between different kinds of sands would not be possible unless a single testing method is used.

Development of Testing Procedure — Fifth Phase Tests

For this phase of testing, the same basic procedures as those developed for the fourth phase were used. The testing difficulties, however, were taken into consideration. Mason jars were used for sand-water rotation and plastic tubes were used for centrifuging. One sample was prepared using sand containing 96% silica plus phenol-formaldehyde resin (same sand as that used in first three phases) to compare release obtained through the rotational mixing technique with release obtained through shaking. Samples for this phase were prepared as follows:

E1 — 100 g phenol-formaldehyde sand in 400 ml water
E2 — 100 g new facing sand in 400 ml water
E3 — duplicate of E2
E4 — 30 g new facing sand in 400 ml water
E5 — 30 g old facing sand in 400 ml water
E6 — duplicate of E5

Centrifuging and filtering of water containing facing sand was found to be workable but very time-consuming. A full work day was needed to centrifuge and filter five facing sand samples. Use of additional laboratory apparatus would reduce the amount of time needed.

This phase of testing was conducted for a period of about 1-1/2 months. Results of analyses are indicated in Fig. 68-70.

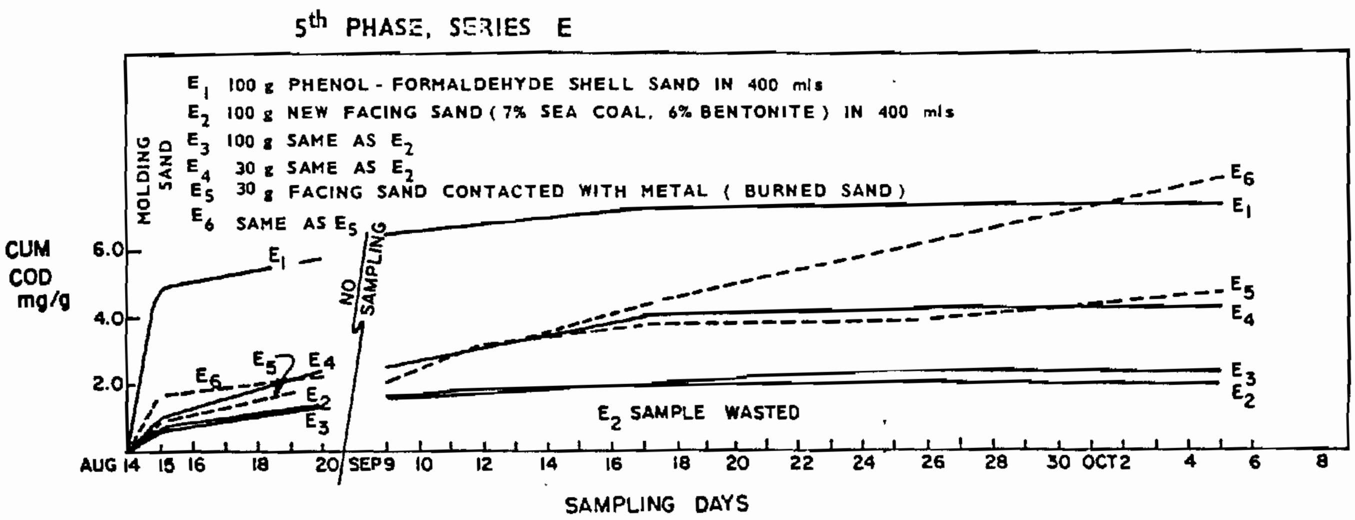


Fig. 68. 5th phase, series E, cumulative COD vs sampling days.

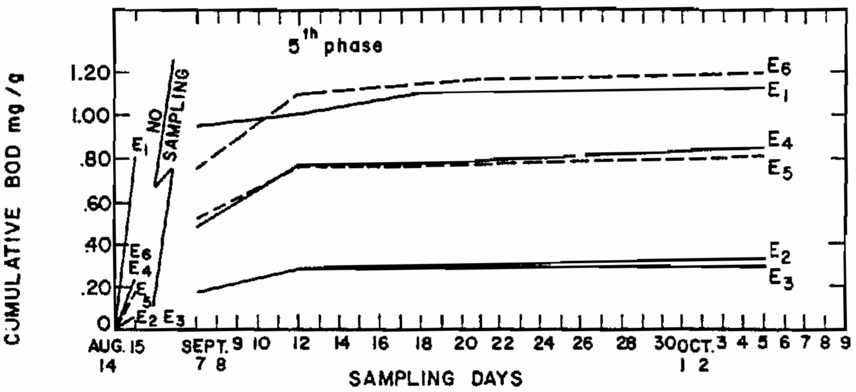


Fig. 69. 5th phase, cumulative BOD vs sampling days.

In a comparison of the COD curve for phenol-formaldehyde shell sand from this test phase with the COD curve from the third phase (Fig. 60), it appears that the technique of intermittent sand-water mixing yields results similar to those of the continuous shaking technique. Both the shape of the cumulative release curve as well as cumulative release values are similar. The sightly less release indicated in this phase appears to be due to a difference in sand-water mixing time.

Examination of cumulative release (COD) over the duration of testing indicates that the slope of the curve becomes negligible after the third or fourth day of sampling (third or fourth elution). This indicates that the technique of intermittent sand-water mixing is adequate to bring about matter release and that the most significant release occurs in the first few periods of testing or elution.

Cumulative COD for the facing sand was significantly lower than COD for the phenol-formaldehyde shell sand.

Good reproducibility of data was obtained from replicate samples E2 and E3, both containing 100 g of new sand in 500 ml of distilled water. For this sand, slopes of the release curves (COD and BOD) also become negligible after the first few periods of testing.

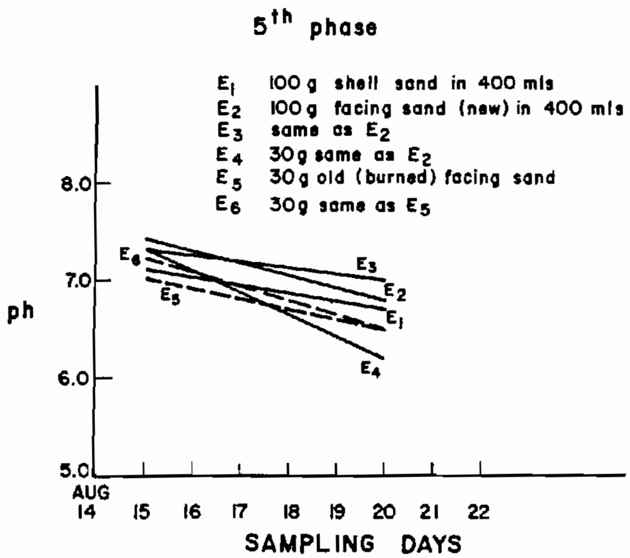


Fig. 70. 5th phase, pH vs sampling days.

With the facing sand in this test phase as with the shell sand in previous phases, release data was not reproduced in samples of different sand-to-water ratios. Again, the samples with smaller sand-to-water ratios produced greater release (mg/l). This result seems to indicate that use of a rotational sand-water mixing technique rather than a shaking technique will not eliminate the difference. It appears that for operational simplicity, the shaker could be used for further testing. However, the shaking should be done intermittently rather than continuously.

At the end of this phase of testing, the equation of what sand-to-water ratio should be used remained unanswered. An additional series of tests was needed to examine that question.

Development of Testing Procedure — Sixth Phase Tests

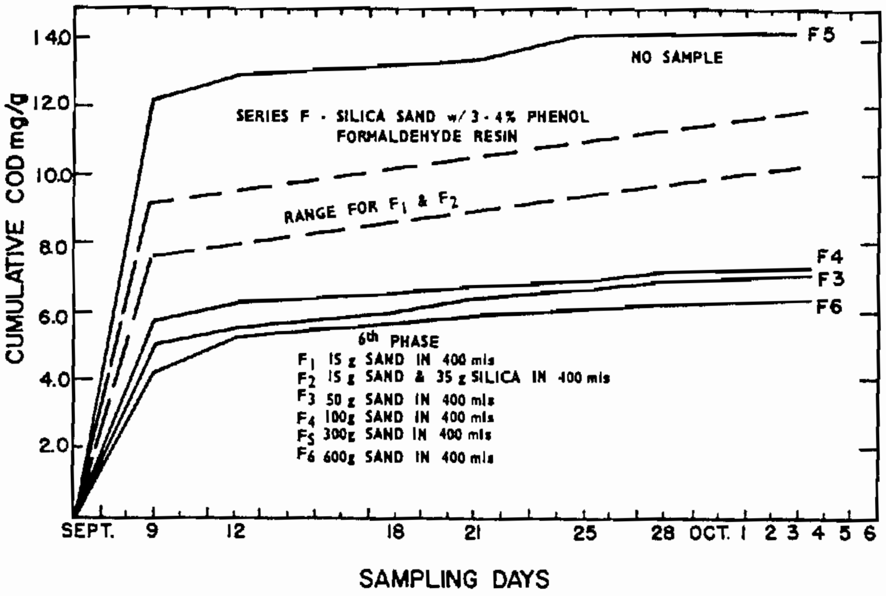
The objective of this phase of testing was to determine the most appropriate sand-to-water ratio to use in test samples. The reciprocating shaker was used intermittently (2 times per day for a duration of approximately 15 sec each) for sand-water mixing. Shell sand with 96% silica plus phenol-formaldehyde resin was used, where the sand-to-water ratios would be grouped to help indicate a degree of reproducibility. It was expected that data scattered outside the groupings might indicate sand-to-water ratios that would yield a degree of unpredictability and unreproducibility.

Results of this series of tests are indicated in Fig. 71-77.

Examination of the curves indicates that three periods of shaking and sampling (three elutions) will be sufficient to predict both the slopes of the release curves, as well as maximum quantities of matter release. Further examination of release concentrations (mg/l) from one sample to another and from one day's sampling to another indicates that solubility limiting conditions are not occurring in the shake flasks. No single release concentration has been repeatedly reached in any of the flasks.

Comparison of release from samples F1 and F2 indicates the negligible effect of the addition of pure silica sand. It appears from these results that relationships between the shaking process and the total number of sand

Fig. 71. 6th phase, cumulative COD vs sampling days.



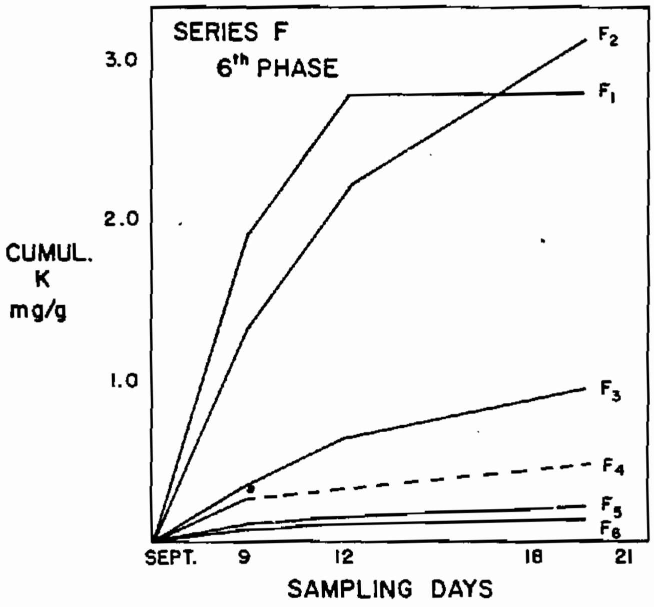


Fig. 72. 6th phase, cumulative K vs sampling days.

particles involved are not the key factors in matter release. Of greater importance appears to be the amount of sand capable of producing significant matter release (i.e. amount of sand coated with resin) and contact or mixing of that sand with water. Due to analytical problems in COD tests for samples F1 and F2, there was not sufficient confidence in the data to allow exact plotting of the curves. However, it was determined that the data would fall in the proximity of the ranges indicated.

Examination of the COD curve for sample F5 indicates that perhaps an unrepresentative sand sample was used or that some amount of impurity was introduced causing excessive oxygen demand. The curves for solids data show F5 to be in the same release range as F4 and F6. Examination of the curve for Zn release substantiates the possibility of impurity in sample F5.

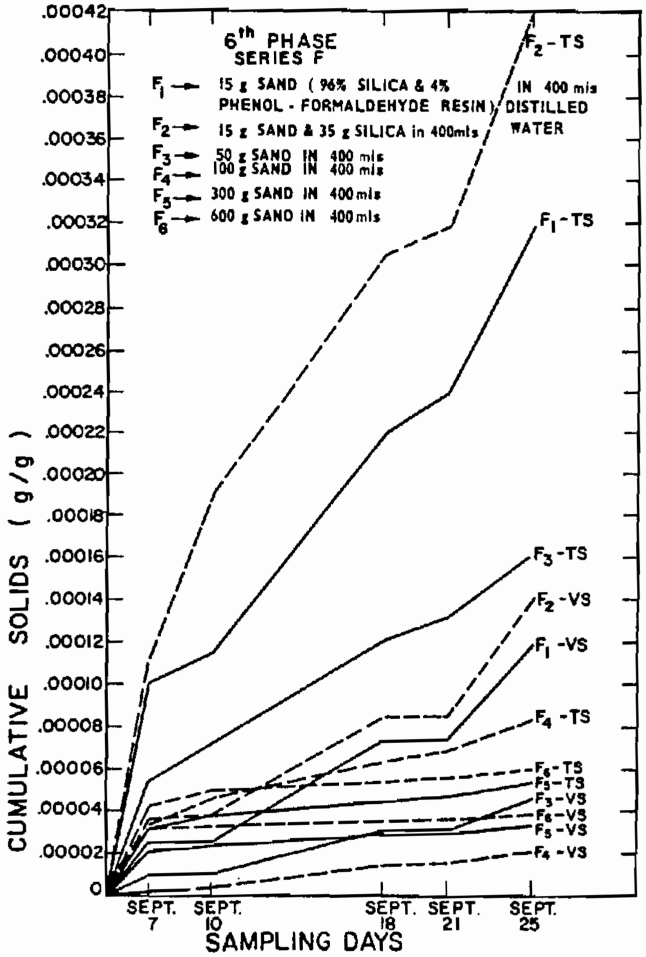


Fig. 73. 6th phase, cumulative solids vs sampling days.

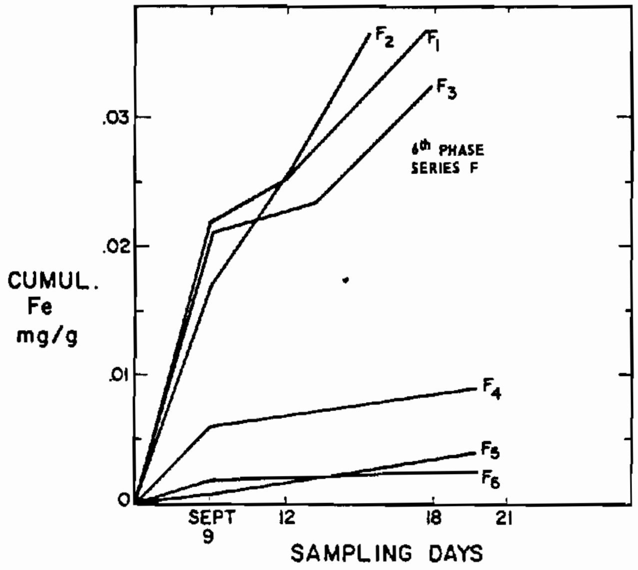


Fig. 74. 6th phase, cumulative Fe vs sampling days.

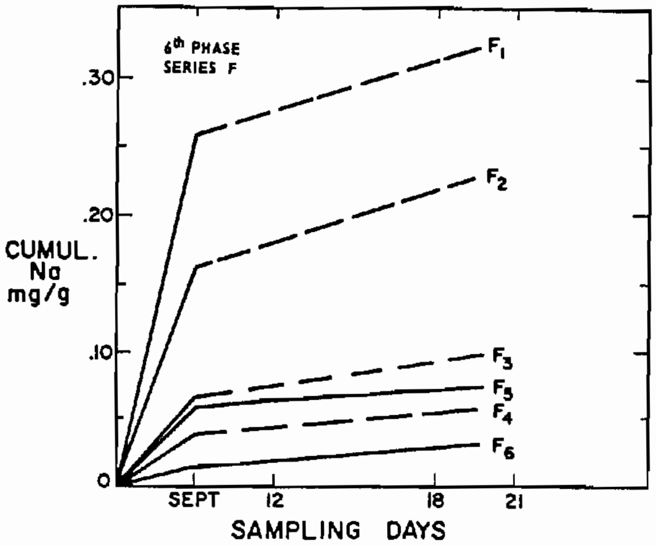


Fig. 76. 6th phase, cumulative NA vs sampling days.

Comparison of release curves for all samples shows a grouping of release data from samples containing 50 g or more shell sand. COD curves for F3 (50 g), F4 (100 g) and F6 (600 g) are intermixed within a fairly narrow range. Solids curves for F4, F5 (300 g) and F6 are intermixed for the first three sampling periods also within a fairly narrow range. On the other hand, COD curves and solids curves for F1 and F2 are far outside these ranges. Curves for metals release generally indicate similar relationships.

From these curves, it appears possible to obtain reasonably reproducible results for samples with different sand-to-water ratios provided the samples have greater concentration than 50 g sand in 400 ml of water. This situation is presented in the curve of total release vs sand-to-water ratio (Fig. 77). Below a sand-to-water ratio of 50 g in 400 ml, any sample impurities and analytical differences or errors would be magnified in computations and data plotting. A reasonable choice for a standard sand-to-water ratio in remaining tests appears to be 100 g of sand in 400 ml of water. Use of this ratio and the standard test procedure should provide a good indication of problem materials and their relative severity and should give a reasonable estimate of the maximum amounts of various matter that might potentially be released.

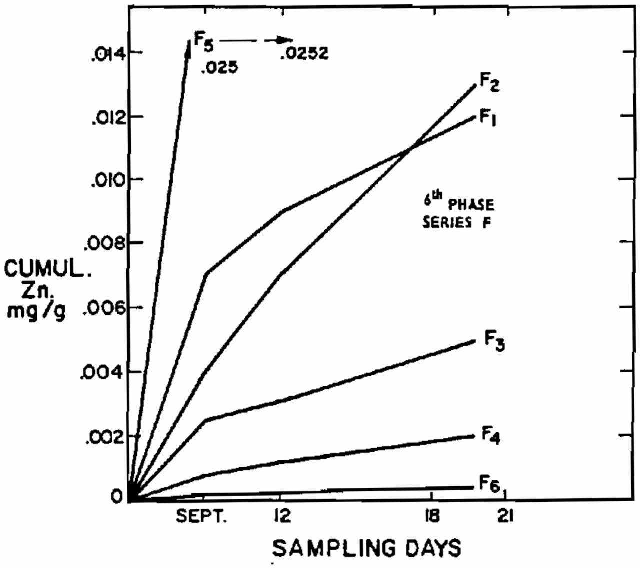


Fig. 75. 6th phase, cumulative Zn vs sampling days.

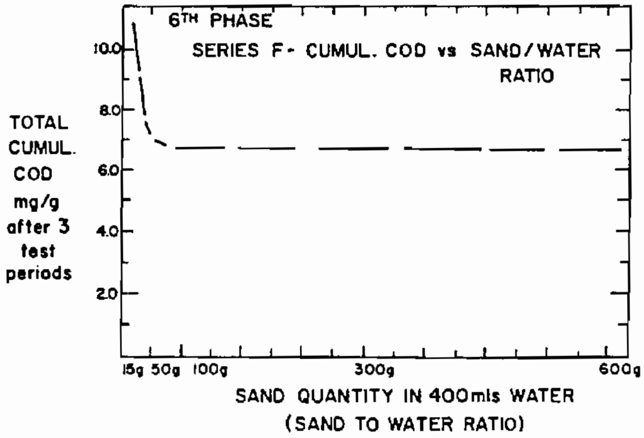


Fig. 77. 6th phase, total cumulative COD vs sand quantity in 400 ml water (sand to water ratio).

4

Moisture Routing in Landfills

In assessment of leachate problems, it is important to know how much of the incident rainfall will result in leachate production over a given time period and the residence time of moisture within the landfill itself.

Water normally reaches the surface of a landfill through precipitation, although runoff from surrounding terrain can also contribute in a poorly engineered and/or operated fill. During a storm, a portion of the precipitation infiltrates into cover material while the remainder runs off. The initial rate of infiltration is large, due to a high matrix tension (suction) gradient, which means that there is a great difference in potential between the wet soil layer at the surface and much dryer soil layers just below. This gradient causes soil to suck into it any water at its surface.

Once water has entered the upper soil layer, it is conducted into deeper soil layers due to the difference in potential between the now wet top soil layer and dryer deep layers. The manner in which this water redistributes itself has been divided into zones. Under a heavy rainstorm, the uppermost layer becomes saturated. Water then moves into a transition zone characterized by a rapid change in moisture content with depth and time. This zone is normally only a few centimeters thick. Water then enters a transmission zone where little change in moisture content occurs with depth. Finally, water reaches the wetting zone where there is again a rapid change in moisture content with depth and time. The deepest part of this wetting zone has a very steep suction gradient and is called the wetting front.

As the wetted portion of the soil profile increases, gravitational forces become dominant and flow approaches the saturated hydraulic conductivity of the fill material. The rate at which the moisture front moves through the fill is also dependent upon the intensity of the rainfall, its duration and frequency. Other factors include initial moisture content, slope and structural characteristics of the soil, amount and type of vegetative cover and the extent of frost penetration.

Water applied to a completed landfill does not result in immediate leachate production. The wetting front must first move completely through cover material and solid wastes. The rate at which this movement occurs is determined in part by the availability of moisture. This is because not all water in the upper soil and waste layers drains away after a rainstorm. Some of it remains behind, held in place by adsorptive and capillary forces. The moisture content which satisfies these forces is called the field capacity. It represents the maximum moisture content which a soil or waste material can retain in a gravitational field without resulting in significant drainage to lower layers. Although field capacity is a function of pore size distribution of the soil or waste, it is not a unique value. It changes depending on the characteristics of the layers immediately above and below it and depends on whether the soil is in a drying or wetting process.

Runoff from the landfill site will occur when rainfall intensity exceeds the infiltrative capacity of the soil. The quantity of runoff is often related to soil type, vegetative cover and slope. For example, flat pastureland on open sandy loam will produce about 10% runoff of the incident rainfall, whereas hilly (10-30%) pasture on tight clay will result in about 60% runoff.

Evapotranspiration* of water within the landfill also plays an important role in leachate generation. Evapotranspiration is dependent upon solar radiation, vapor pressure gradient, advection, vegetative cover and heat production within the fill material. It is also necessary that the matric** potential and the fill be high enough to pull liquid from the high moisture regions within the fill toward the surface. This capillary pull is dependent upon grain size distribution of fill material and may range from about 35 cm of water in coarse sands to as high as 100 cm in a heavy loam.

Estimation of Flow in Landfills

Dynamics of fluid flow through landfills is highly complex and a completely satisfactory model is not available for predicting flow rates. In general, flows will be site-specific and should be characterized for climatological features in the area of the landfill.

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* Loss of water from soil through evaporation and transpiration from plants growing in that soil.

** Draw of water through successive layers of a landfill matrix due to capillary action, gravity and so forth.

Table 16. Typical Values of K_{sat} (Hough, 1969)

	cm/sec
Uniform, fine sand	4×10^{-3}
Well-graded, silty sand and gravel	4×10^{-4}
Silty sand	1×10^{-4}
Uniform silt	5×10^{-5}
Sandy clay	5×10^{-6}
Silty clay	1×10^{-6}
Clay	1×10^{-7}

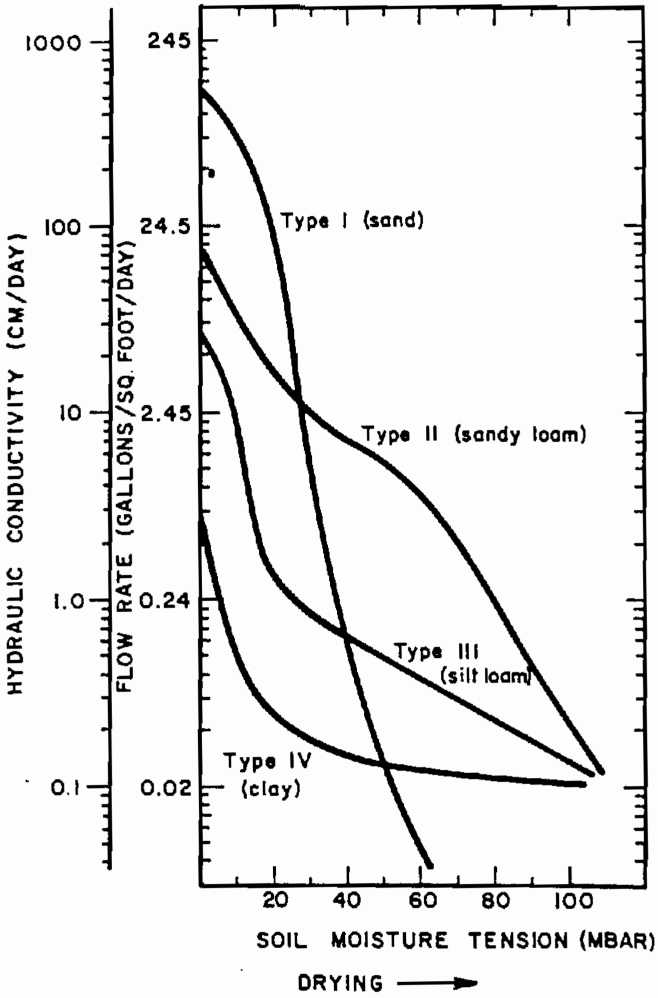

Fig. 78. Hydraulic conductivity (K) as a function of soil moisture tension (Bouma 1973).

Steady-state flow in saturated porous media can be estimated by Darcy's Law:*

$$Q = KA\,(\Delta H/L) = KAI$$

where:

Q = quantity of water per unit time
K = coefficient of permeability of the material (the modern term for this is hydraulic conductivity)
A = cross-sectional area of the sample
ΔH = headloss through the sample (for saturated flow in an unconfined material, this is simply the loss in gravitational potential)
L = sample length
I = $\Delta H/L$ = hydraulic gradient or headloss per unit length.

The saturated hydraulic conductivity, K_{sat}, for a given material can be determined analytically with various types of permmeters. The value of K_{sat} is dependent upon water temperature, increasing with increased temperature. K_{sat} decreases as average particle size of a soil decreases and decreases with decreasing void ratio (increased compaction). Typical values of K_{sat} for selected soils appear in Table 16.

The driving force, or gradient $\Delta H/L$, in saturated soils is dominated by the gravitation force, ψ_g and would have a value of 1 cm/cm.

Darcy's Law will also apply to flow through unsaturated soils. In this case, however, the headloss must include the loss in total potential; thus,

$$\Delta H/L = \psi_g + \psi_m + \psi_\pi + \psi_\Omega$$

where

ψ_g = gravitational potential
ψ_m = matric potential
ψ_π = osmotic potential
ψ_Ω = overburden.

In addition, hydraulic conductivity, K, of the soil decreases markedly (depending upon the soil) as moisture content decreases. This is the result of reduction in the number of pores conducting flow. Plotting hydraulic conductivity, K, for different matric potentials produces a curve unique for a given soil type. Typical curves are presented in Fig. 78.

Computation of steady-state, unsaturated flow requires a hydraulic conductivity function for the porous media and a measure of the total potential difference existing within the fill. It is apparent, from Fig. 78, the unsaturated flow conditions greatly reduce total rate of flow generated in landfill situations over that estimated by Darcy's Law for saturated flow.

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*The velocity of flow of a liquid through a porous medium due to difference in pressure is proportional to the pressure gradient in the direction of flow.

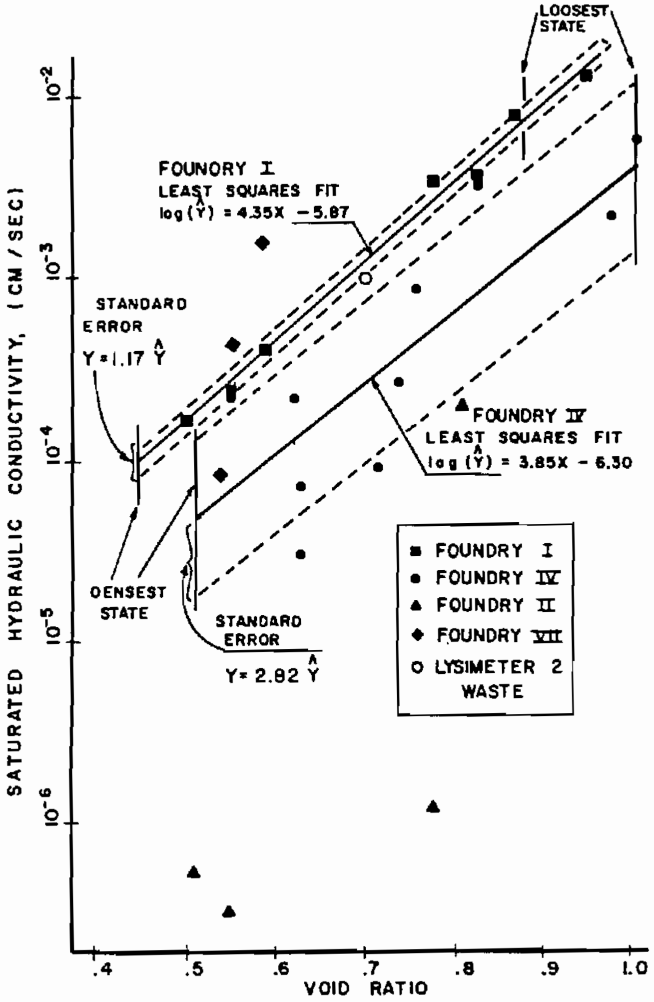

Fig. 79. Saturated hydraulic conductivity of wastes containing foundry process sand.

As indicated previously, flow regimes through porous media receiving natural rainfall occurrences will not exist at steady-state. Unsteady-state conditions at unsaturated flow require additional, more complex mathematical expressions[24,25] and are beyond the scope of this report. More detailed treatment of flow dynamics in porous media can be found in Hillel,[24] Childs,[25] Rose[26] and Bouma.[27]

Examination of water balances within a landfill suggests a more simplistic procedure that might be used to roughly estimate leachate production in landfills.

Infiltration can be estimated by the simple material balance:

$$Q_I = Q_R - Q_{RO} - Q_E$$

where

Q_I is infiltrative flow
Q_R is incident rainfall
Q_{RO} is runoff
Q_E is evaporation

all in similar units.

Runoff of rainfall from land surfaces has been studied for many years by engineers and simple mathematical relationships have been derived to relate runoff to soil type, vegetative cover, topography and rainfall intensity, frequency and duration. Assuming that the rational formula, $Q = CIA$, is valid for small areas such as landfills, one can estimate the percent of precipitation which will run off a given fill under a given set of conditions. Values of C for selected soil types, vegetative cover and slope are presented in Table 17.

Estimates of evaporation from landfills are more difficult to evaluate. Evaporation is dependent upon solar insolation, vapor pressure gradient, advection and transpiration. Grain size distribution within the landfill is also important, as mentioned earlier, since the holding and lifting capacity (matrix potential) of the fill will dictate the amount of water available at the surface for evaporation. Additional field data will be necessary to more effectively determine this factor.

Hydraulic Characteristics of Foundry Solid Wastes

Saturated hydraulic conductivities were measured for process solid wastes from four foundries using constant head and variable head techniques. Characteristics of these foundries are presented in Table 18. Results of these tests are presented in Fig. 79. As predicted by theory, for a

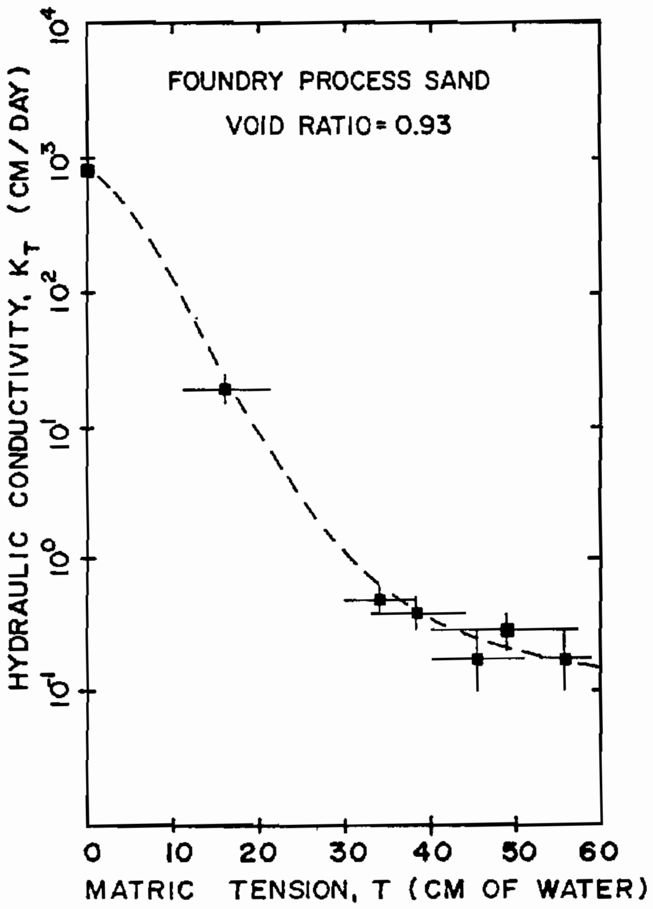

Fig. 80. Hydraulic conductivity as a function of matric tension.

Table 17. The Rational Formula and Typical Runoff Coefficients (Adapted from Frevert et al, 1963)

$$Q = CIA$$

where

Q = quantity of runoff
C = runoff coefficient
I = rainfall intensity
A = basin area

Slope	Open Sandy Loam	Clay and Silt Loam	Tight Clay
Pasture or meadow (surface with cover crop)			
Flat (0-5% slope)	0.10	0.30	0.40
Rolling (5-10% slope)	0.16	0.36	0.55
Hilly (10-30% slope)	0.22	0.42	0.60
Cultivated (raw soil surface)			
Flat (0-5% slope)	0.30	0.50	0.60
Rolling (5-10% slope)	0.40	0.60	0.70
Hilly (10-30% slope)	0.52	0.72	0.92

Table 18. Description of Foundry Processes of Lysimeters With Total Waste Stream**

Lysimeter	Foundry Processes
Foundry II*	Ductile iron; basic water-cooled cupola duplexing to channel induction furnaces; western bentonite bonded green sand; shell cores; seacoal substitute as sand additive.
Foundry IV	Gray and ductile iron; basic and acid water-cooled cupola duplexing to channel induction furnaces; western bentonite bonded green sand; shell, nobake, CO_2 and oil sand cores; seacoal sand additive.
Foundry I	Malleable iron; acid-lined coreless induction melting; southern and western bentonite bonded green sand; shell, CO_2 and oil sand cores; seacoal sand additive.
Foundry VII	Copper-base; crucible and induction melting; southern and western bentonite bonded green sand; shell, nobake and CO_2 sand cores; no sand additive.

* Foundry number was assigned from earlier studies reported by Santa Maria, Heine and Loper (1974), and Heine, Loper, Santa Maria and Nanninga (1975).
** A lysimeter is a device for measuring the percolation of water through soils and determining the soluble constituents removed in the drainage.

given grain size distribution, K_{sat} increases with increased void ratio. Lowest K_{sat} values were reported for foundries employing western bentonite (foundry II and foundry IV). Foundry II contains significantly more clay than foundry IV. Results of these tests indicate a wide variation in K_{sat} between foundries. These process wastes behave hydraulically like soils ranging from fine sands to silty clays (Table 16).

Unsaturated hydraulic conductivities were also reported by Kmet.[28] A typical curve is presented in Fig. 80. Comparison of this curve with those in Fig. 78 suggests that this foundry process waste is hydraulically similar to a silt loam. No data was collected for the other foundry wastes.

Lysimeter Studies Under Controlled Environment

To better characterize the real-world behavior of foundry solid waste landfills with respect to leachate generation, an intermediate level of testing was undertaken at the University of Wisconsin. For this purpose, lysimeters, 2 x 2 x 1.5 ft deep, holding approximately 600 lb of solid waste were used. A detail of these lysimeters appears as Fig. 81. The lysimeters were placed in a controlled environment facility wherein temperature, humidity, rainfall and solar insolation were controlled. Meteorological records for the Detroit, Michigan, area were used to develop this simulation. To reduce the test period, the simulated day was compressed to 8 hr; thus, the 6-month real-time experiment simulated an 18-month weather cycle.

In these studies, process solid wastes from four foundries were selected. A description of these foundries and the composition of the solid wastes is given in Tables 18 and 19.

The experimental design for these lysimeter experiments is schematically depicted in Table 20. Actual foundry process solid wastes were placed in four of the lysimeters. However, since preliminary moisture routing experiments indicated that foundry solid wastes containing green sand bonded with western bentonite could be relatively impervious, a number of lysimeters were prepared using a synthetic system sand with a clay content of 0.75%. A selected number of lysimeters were also prepared in which core butts were removed from the process waste. Finally, one lysimeter cell was completed with the top sloped to a 3% grade.

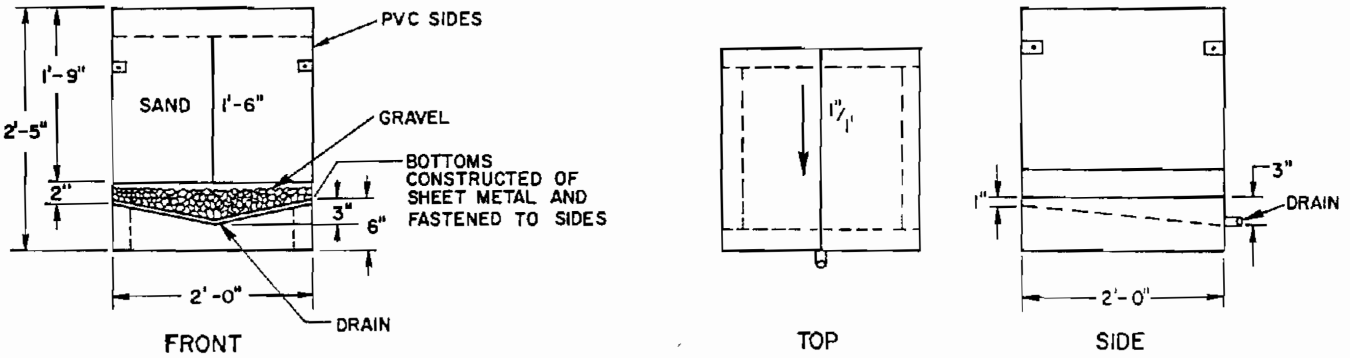

Fig. 81. Drawings of a lysimeter (for biotron studies).

Table 19. Composition of Foundry Waste Mixtures

Material	I	II	IV	VII
	Percentage of Total by Weight			
Refractories	2.25	1.82	1.09	13.53
Systems sand	70.12	75.70	51.83	35.50
Core butts	14.79	2.93	10.11	28.03
Core sweepings	2.81	0.65	3.67	20.77
Annealing room waste	2.47	—	—	—
Cleaning room waste				
Grinding	0.16	—	0.06	—
Steel shot	0.55	—	0.45	—
Other	0.06	3.01	—	—
Slag and coke ash	5.39	15.89	20.83	—
Dust collector discharge	1.12	—	9.84	2.17
Scrubber discharge	—	—	2.12	—
Totals	**100**	**100**	**100**	**100**

Details of experimental design, results and discussion for the lysimeter study can be found in Liu.[29] A synopsis of significant findings of this study is given below. Data will be presented for the four foundry process waste lysimeters.

Table 20. Experimental System for Lysimeters

Condition	Foundries			
	I	II	IV	VII
Total waste	3*	1	2	10
Synthetic systems sand	5	11	7	—
Synthetic systems sand, no core butts	4	8	9,12	—
3% Top slope	6	—	—	—

*Lysimeter number

Moisture Routing

Rainfall durations, frequencies and intensities were applied in accordance with meteorological records at Detroit, Michigan. Rain intensities ranged from 0 to 6 in./month depending upon the season of the year. Total accumulative rainfall during the 18-month study is depicted in Fig. 82. Routing of moisture in the 12 lysimeters is depicted in bar graph form as Fig. 83. Collection of leachate from the four lysimeters holding actual foundry wastes is shown in Fig. 84 and a moisture budget for all 12 lysimeters appears in Table 21. Data in Table 21 is adjusted to eliminate that period when leachate was first generated.

Drain-off from those lysimeters which were so impermeable as to lead to surface ponding was such that water stood on the lysimeters for several days before being removed (except for the sloped lysimeter). In addition, the shallow depths of these lysimeters may have enhanced evaporation of water held within the fill material. Thus, reliable comparison of actual leachate generation rates for full-scale landfills of similar waste composition is not possible.

Table 21. Water Budget for Lysimeters

Lysimeter Number/ Foundry Represented	Days After Initiation of Test Leachate First Collected	Adjusted Rainfall (liters)	Amount of Leachate Produced (liters)	% Rainfall Recovered as Leachate	% Rainfall Recovered as Drainoff
1/II (4.5)^1	52	337	44	13.2	25.9
2/IV (3.1)^1	24	530	149	28.2	3.2
3/I (4.2)^2	4	583	199	34.1	—
4/I (0.6)^1	3	575	158	27.4	—
5/I (0.5)^1	21	533	182	34.1	—
6*/I (0.5)^1	3	594	56	9.4	40.8
7/IV (0.5)^1	3	562	199	35.4	—
8/II (0.6)^1	5	432	87	20.2	—
9/IV (0.4)^1	25	519	147	28.4	—
10/VII (2.1)^2	2	710	229	32.3	—
11/II (0.6)^1	2	452	201	44.4	—
12/IV (0.5)^1	2	283	184	65.0	—

*Lysimeter #6 was sloped at 3% with instantaneous runoff collection provisions

( )^1 - Percent clay - western bentonite

( )^2 - Percent clay - southern bentonite

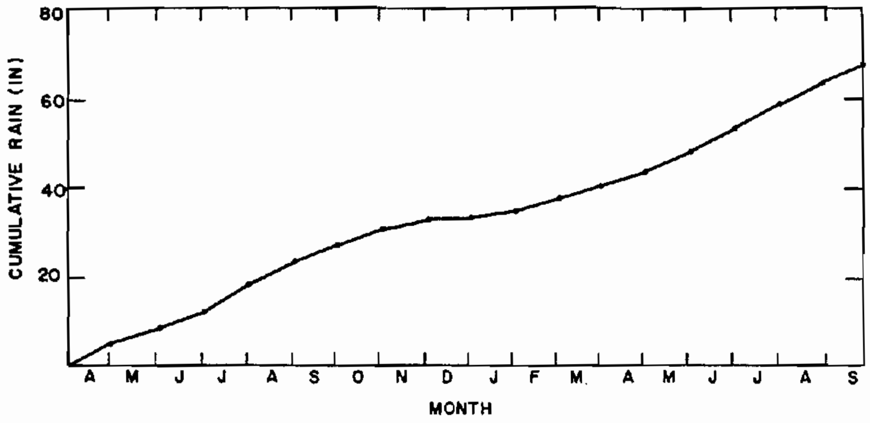

Fig. 82. Average cumulative rain applied-lysimeters.

Review of this data does suggest, however, several important moisture-routing characteristics of foundry solid waste landfills. It is apparent that sodium-based clays (western bentonite) initially produce an impermeable flow condition in foundry solid waste landfills (lysimeters 1 and 2 vs 11 and 7). However, these clays undergo change with time due to exchange reactions. Once sodium is released, the clays may shrink and flocculate, becoming more permeable to flow. This is clearly demonstrated for foundries II and IV (lysimeters 1 and 2) (Fig. 84). Sloping of landfill sites will promote runoff as predicted, thereby reducing infiltration and subsequent leachate production. The 3% slope (lysimeter 6) resulted in approximately 40% runoff (range 28-56%) producing about one-third the leachate found on a similar waste with a flat surface (lysimeter 5).

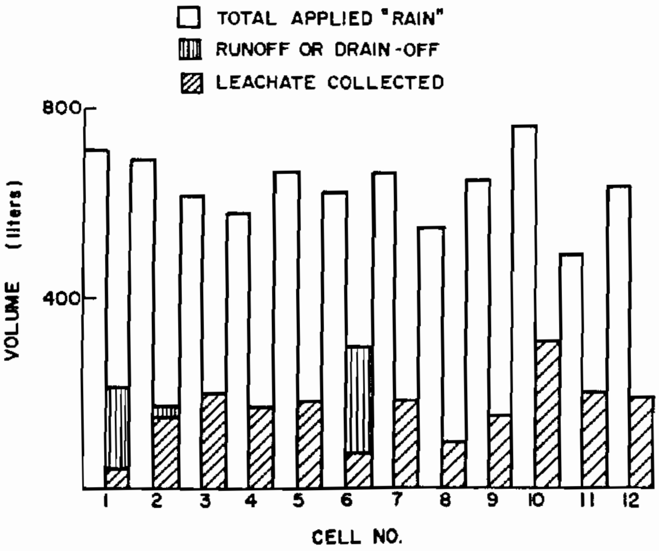

Fig. 83. Water budget for controlled lysimeter studies.

The lysimeter studies were useful in providing relative values of leachate flow and quality but absolute values of leachate generation are site-specific. As mentioned earlier infiltration is influenced by fill characteristics, vegetal cover, rainfall intensity, area slope, temperature and conditions of the surface crust. Analysis of leachate generation in these test lysimeters, as a function of saturated hydraulic conductivity (Fig. 85), indicates a definite decrease in leachate production with decreased saturated hydraulic conductivity but a generalized relationship would be inappropriate based on this rather meager data base. Observations of leachate flows in these lysimeters indicate that once the fills reached field capacity, leachate flows were dependent upon precipitation duration and frequency, except in those fill systems containing western bentonite where gradual increases were noted to occur during the 18-month sequence. It was also observed that absence of core butts in the foundry waste produced no consistent effect on leachate production.

Examining hydraulic characteristics of the foundry solid wastes used in this study suggested that they behaved like soils ranging from a fine sand to a silty clay. Assuming runoff coefficients of 0.30-0.50, as given in Table 17, one would conservatively calculate leachate production ranging from 70% for the fine sand (foundries VII and I) to 50% for the silty clay (foundry II). Based on lysimeter measurements of leachate generation in these studies, one might estimate 40% evaporative losses. (Actual losses were substantially higher than this, owing to shallow lysimeter configuration and inadequate surface water removal.) Studies of a number of large field lysimeters (30 x 4 ft deep) constructed of mixed residential refuse covered with sandy-silt, highly vegetated and sloped to 3%, resulted in approximately 20% leachate, 8% runoff and 72% evapotranspiration (Ham and Karnauskes[30]). It should be cautioned that these studies were conducted with a fill material substantially different than foundry process solid wastes in relatively shallow lysimeters and covered with a heavy vegetative cover. Yet, it is apparent from these illustrations that the use of runoff only to estimate leachate production will probably overestimate production. Evaporation corrections should be made and can be properly estimated only through additional field research evaluation.

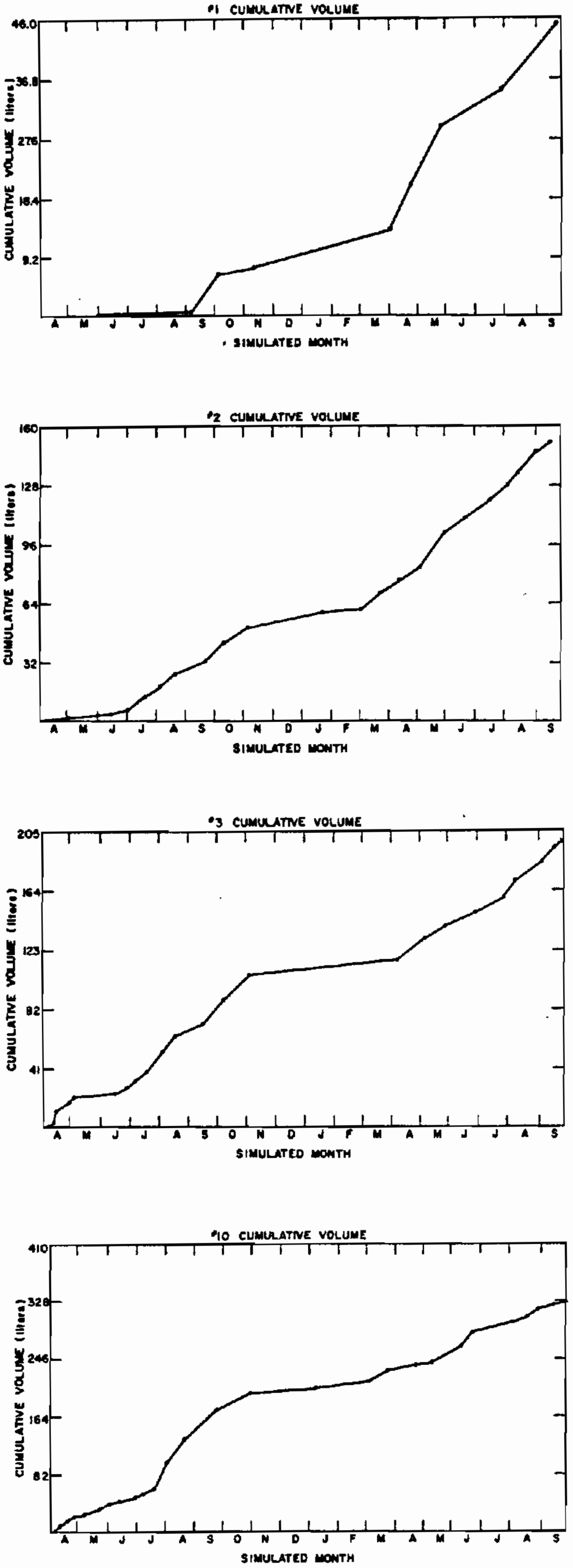

Fig. 84. Accumulation of leachate for four foundries—lysimeter studies.

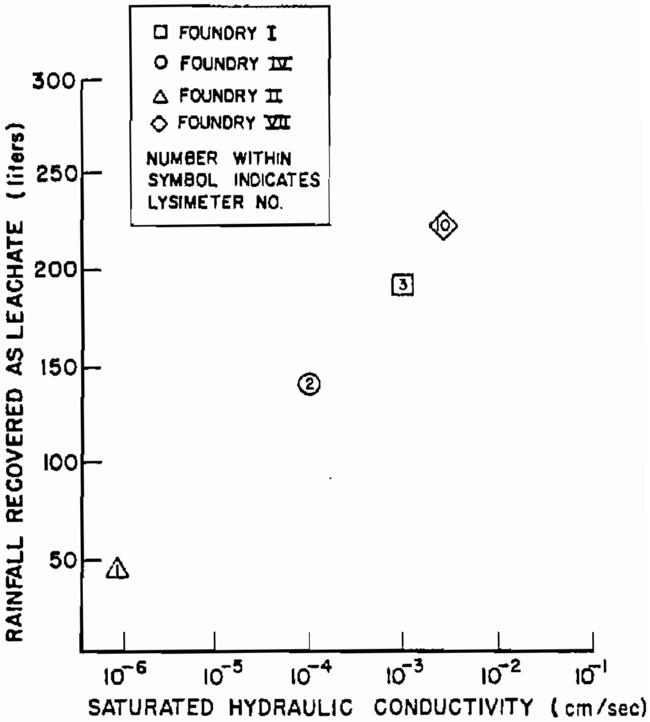

Fig. 85. Leachate production as a function of the saturated hydraulic conductivity.

Leachate Quality

The results of lysimeter leachate quality analyses for selected pollutants are presented in Fig. 86-91 and are summarized in Table 22.* Graphical presentations are based on total cumulative pollutants and illustrate the dynamics of leachate generation. Table 22 presents maximum concentration of pollutant recorded, average concentration over the first year and average concentration over the first 18 months. In most instances, maximum concentration was observed shortly after leachate production.

Organic carbon and COD analyses are measures of organic matter leached from the fill material. BOD, a measure of biodegradability, was also occasionally monitored but values were inconsistent with organic levels monitored (BOD_5 ranges were from 13 to 1 mg/l). This was probably due to toxic effects of the leachate on unacclimatized bacterial seed used in these tests.

Highest organic carbon and COD values were recorded for foundries VII and IV. The highest percentage of core butts and sweepings was discharged by foundry VII (Table 19) and foundry IV waste sands contained the highest combustible content. Removal of core butts from process sand produced only minor reductions in COD accumulations in leachate, however (lysimeters 5 vs 4, 11 vs 8 and 7 vs 9, 12).

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* Data presented is only for lysimeters 1, 2, 3 and 10 containing process sands.

Table 22. Lysimeter Results—18 Simulated Months

Component	Concentrations in Leachate/Foundries											
	I			II			IV			VII		
	max	1 yr	18 mo	max	1 yr	18 mo	max	1 yr	18 mo	max	1 yr	18 mo
Organic carbon (mg/l)	14	5	4	31	15	13	120	80	70	185	35	27
COD (mg/l)	75	30	25	240	100	90	290	230	225	1100	260	260
Phenol (μg/l)	25	14	12	78	16	15	400	120	110	52	18	15
Cyanide (μg/l)	—	—	—	80	—	<20	—	—	—	<20	—	<20
Fluoride (mg/l)	3	—	—	32	25	20	120	65	80	3	—	—
Sulfates (mg/l)	30	—	—	1220	—	(800)	1120	—	(600)	78	—	—
pH Range	7.6-8.0—			8.0-8.8→			7.2-10.0↑			7.3-8.0↓		

( ) — Estimate value
↑↓ — Increase/decrease
— — Steady

The organic components in leachate appeared to decrease in concentration with time. Cumulative curves suggest that major pollutional contribution would occur in the first 1 or 2 years of active leachate generation.

High phenol levels were found in leachates from foundry waste sands using phenolic resins as well as coke. Dust collector dust was especially high in phenol from foundry IV. Lysimeters with low clay content but with other waste constituents held constant produced higher phenols. Phenol concentration decreased rapidly with time during the 18-month test.

Cyanides leached only early in the study. No cyanide was detected in leachate after several months of leachate generation (<0.1 mg/l). Cyanide was detected only from foundries IV and VII, where phenol-isocyanate and alkyd-isocyanate cores were used.

Appreciable concentrations of sulfates and fluorides were found in leachates from foundries using basic cupolas and fluorspar slag fluxes. Leaching of these materials appeared to be persistent even after 18 months of leaching.

The pH values of leachates were all in the alkaline range. Highest values were found from fills containing western bentonite. Sodium carbonate associated with this clay probably produces this effect. Presence of CO_2 sands depressed pH toward neutrality as is illustrated by foundry VII.

Concentrations of metals found in leachate during this study are tabulated for the four foundries in Table 23. It is significant that heavy metal concentrations are very low except for iron which ranged from 0.1 to 0.4 mg/l. These low values may be attributed to high pH and subsequent

Table 23. Metals Release Data—Lysimeter Studies

Foundry	Date	P	K	Ca	Mg	Na	Al	Ba
I	9/2	<5.00	<20.0	68.1	12.3	290	<0.200	<0.0400
	11/23	<5.00	<20.0	29.3	4.92	136	<0.200	<0.0400
	1/4	<5.00	<20.0	31.7	4.92	63	<0.200	<0.0400
II	9/23	<5.00	59.4	98.4	48.9	2330	0.217	<0.0400
	12/9	<5.00	<20.0	30.8	4.43	575	<0.200	<0.0400
	1/18	<5.00	<20.0	27.7	7.2	435	<0.200	<0.0400
IV	8/16	<5.00	<20.0	85.3	38.2	1010	<0.200	<0.0400
	9/18	<5.00	<20.0	55.5	7.11	869	<0.200	<0.0400
	1/2	<5.00	<20.0	<10.0	<2.00	438	<0.200	<0.0400
VII	8/2	<5.00	<20.0	52.0	13.2	495	<0.200	0.0863
	9/30	<5.00	21.1	64.9	13.0	164	<0.200	0.107
	12/31	<5.00	<20.0	70.2	12.4	109	<0.200	0.131

	Parts Per Million						
Foundry	Fe	Sr	B	Cu	Zn	Mn	Cr
I	<0.100	1.96	0.0667	<0.0200	1.75	0.0477	<0.0600
	<0.100	0.832	<0.0200	<0.0200	0.333	<0.0400	<0.0600
	<0.100	0.953	0.120	<0.0200	0.135	<0.0400	<0.0600
II	0.125	1.86	0.0684	0.0427	4.68	0.245	<0.0600
	0.429	0.580	<0.0200	0.0427	0.718	0.0462	
	0.100	0.396	<0.0200	0.0380	1.60	<0.0400	<0.0600
IV	0.300	0.272	0.2	0.0661	3.27	0.0569	<0.0600
	<0.100	0.364	0.0732	0.0629	2.59	0.0762	<0.0600
	0.156	0.0540	0.0651	0.168	0.614	<0.0400	<0.0600
VII	<0.100	1.17	16.6	1.57	6.42	0.319	<0.0600
	<0.100	1.39	19.4	1.21	15.3	1.22	<0.0600
	<0.100	1.54	17.4	1.03	7.22	1.01	<0.0600

Table 24. Comparisons Between Shake Flask Release and Lysimeter Release

Foundry	COD Release - mg/g			Phenol Release - µg/g		
	Component[1]	Mix[2]	Lysimeter[3]	Component[1]	Mix[2]	Lysimeter[1]
I	0.408	0.4	0.0187	0.053	0.8	0.009
II	0.218	0.2	0.0145	0.026	0.16	0.003
IV	0.853	0.4	0.1240	0.268	6.12	0.062
VII	0.828	0.8	0.2920	0.052	1.71	0.017

[1] By calculation — see Table 6
[2] By analysis of mix — see Table 7
[3] After 18 simulated months of operation

precipitation of the metals as insoluble carbonates or hydroxides. Highest metal levels were reported from foundry VII, possibly because of the lower pH.

High sodium levels were detected in fills high in western bentonite. As mentioned earlier, sodium may be exchanged from the clays, being replaced by higher valence cations.

A comparison between the quantities of COD and phenol leached in these 18 simulated months and the two shake-flask analyses reported earlier is shown in Table 24. It is clear that shake-flask values are always higher, as would be expected. Between 6 and 35% of the COD predicted by the shake flask was recovered in the 18-month period. There is evidence, however, that additional COD will leach out over some period in the future. Between 10 and 30% of the ultimate phenol was leached in lysimeter tests in 18 months based on the component batch test analysis. Phenol release from the lysimeters had become very low at the end of this 18-month study.

The lysimeter studies have provided some insight into the dynamics of leachate generation in foundry solid waste landfills. Although each landfill must be evaluated on a site-by-site basis, it seems clear that major pollutional problems from landfills, if they exist at all, will occur within a 1- or 2-year period. Normally, maximum leaching of pollutional constituents occurs shortly after leachate generation begins and falls off with time. Batch tests conducted in the laboratory will provide an upper bound to the total pollutant that might be produced. Evidence to date suggests that actual amounts of pollutant leached in a given landfill will be dependent upon the pollutant, its source and environmental conditions within the landfill itself.

To provide some perspective in evaluating data from Table 22, the concentrations of pollutants from several other selected waste sources are presented in Table 25. It is apparent that foundry leachates may exhibit concentrations of pollutants many times lower than those in urban landfills, especially a year after generation.

Conclusions

Information needed by the foundry to properly assess the impact of leachate generation by solid waste landfilling includes:

1) quantity of leachate generated
2) concentration of contaminants produced
3) time distribution of contaminant production
4) assimilative capacity of the soil system to handle these pollutants.

Moisture routing in landfills is site- and waste-specific but measures can be taken to reduce percolation of rainwater into landfills. Field studies, undertaken over an extended period of time, will be useful in developing a model of moisture routing under a given climatological condition. Currently, a conservative estimate of leachate generation can be made from rainfall-runoff relationships. This estimate will over-predict leachate production and should be corrected with evaporation data.

Ultimate leaching potential of selected components within a solid waste mixture can be estimated with a simple laboratory test. Leachate assessment for different products, inplant processes and landfill procedures can be evaluated with this test. Actual leachate characteristics are site- and waste-specific but batch testing will provide a conservative estimate of ultimate expected values.

Table 25. Ranges of Pollutants in Selected Wastes

Component	Foundry Leachate	Urban Landfill Leachate	Septic Tank Effluent
Organic carbon (mg/l)	4-185	250-28,000	25-200
COD (mg/l)	25-1,100	100-51,000	250-1,000
Phenol (µg/l)	12-400	—	0-300*
Cyanide (µg/l)	20-80	—	—
Sulfate (mg/l)	30-1,200	25-1,500	10-600
Fluoride (mg/l)	3-120	—	0-10
Iron (mg/l)	0.1-0.5	200-1,700	0-20
Zn (mg/l)	0.1-15	1-135	0.15*
Ni (mg/l)	0-0.6	0.01-0.8	0.02
Cu (mg/l)	0.02-1.6	0.1-10	0.1*
pH	7.2-10.0	4-9	6.8-8.5

*Municipal wastewater effluents

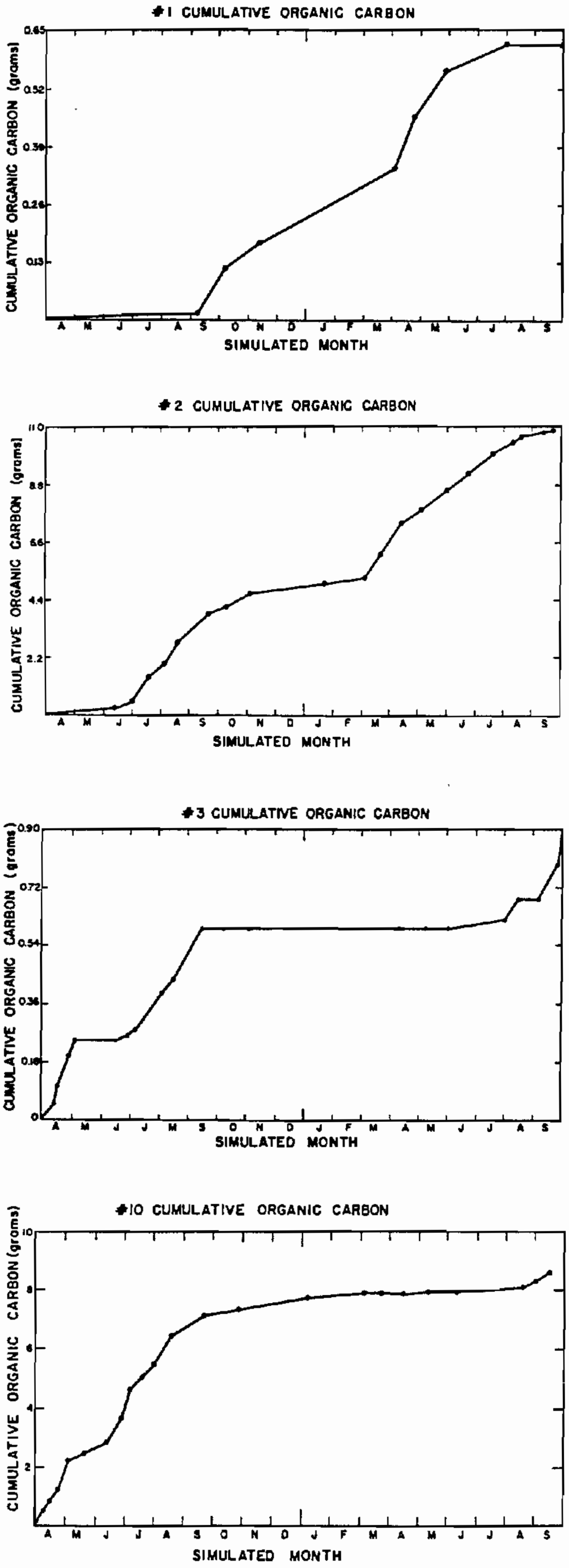


Fig. 86. Organic carbon leachate accumulation for four foundries—lysimeter studies.

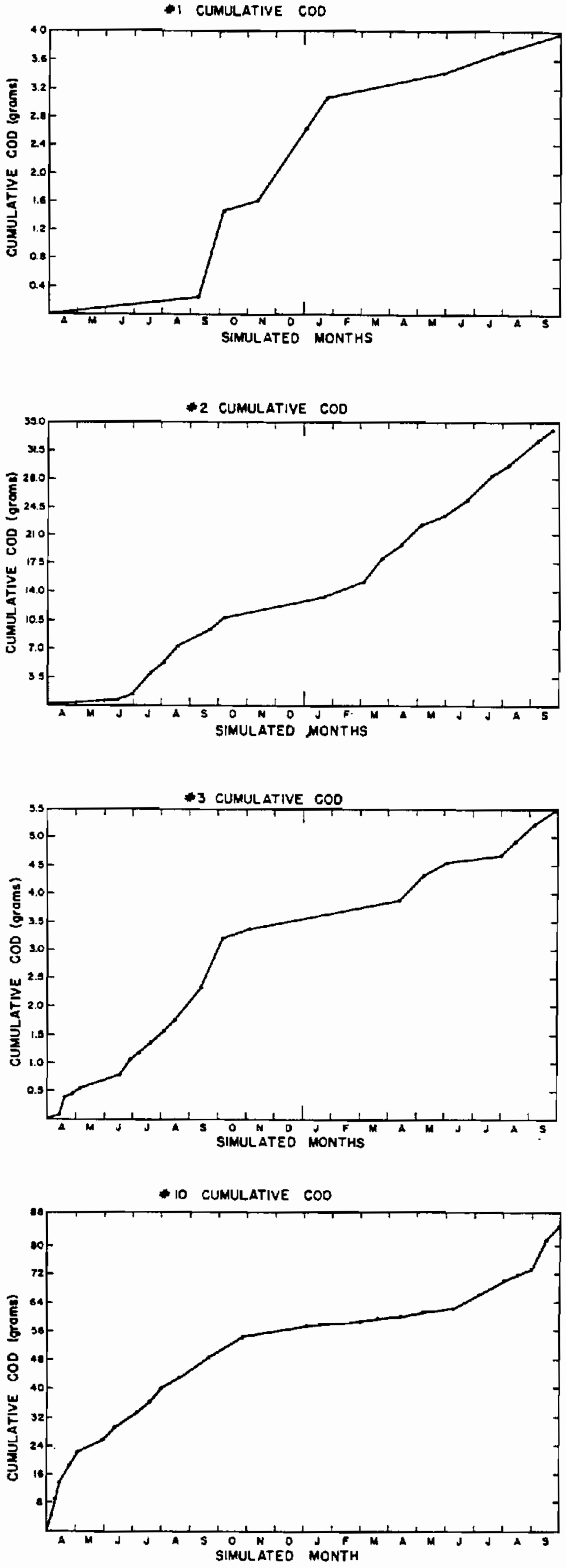
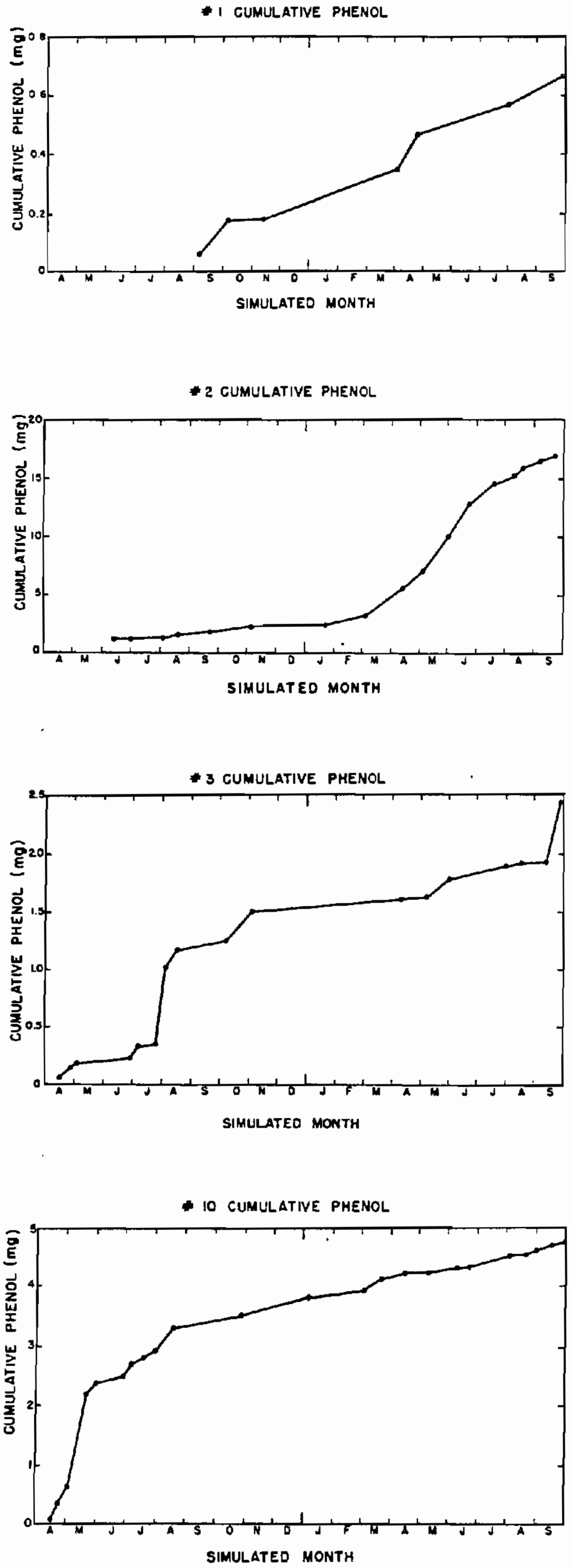


Fig. 87. COD leachate accumulation for four foundries—lysimeter studies.

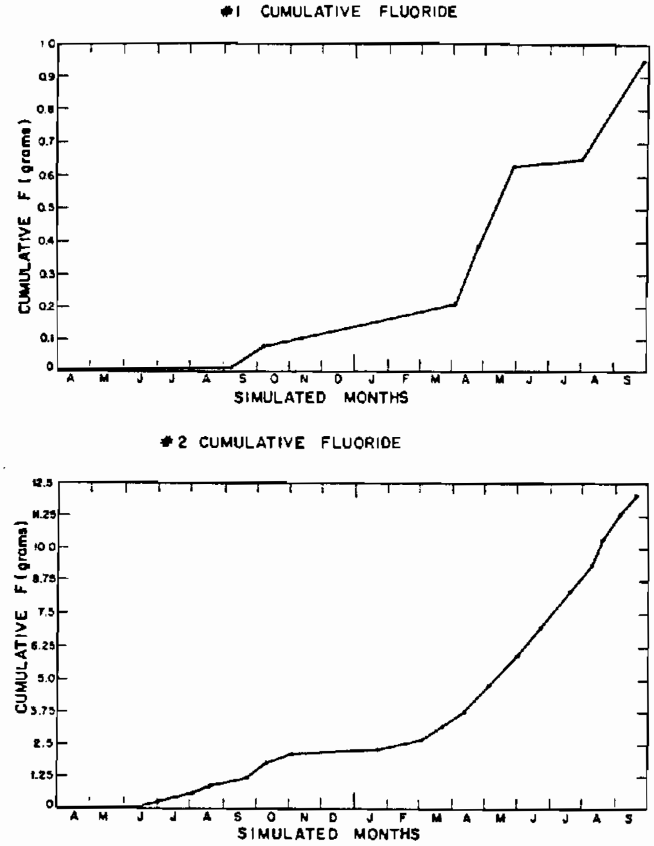

#1 CUMULATIVE PHENOL

#2 CUMULATIVE PHENOL

#3 CUMULATIVE PHENOL

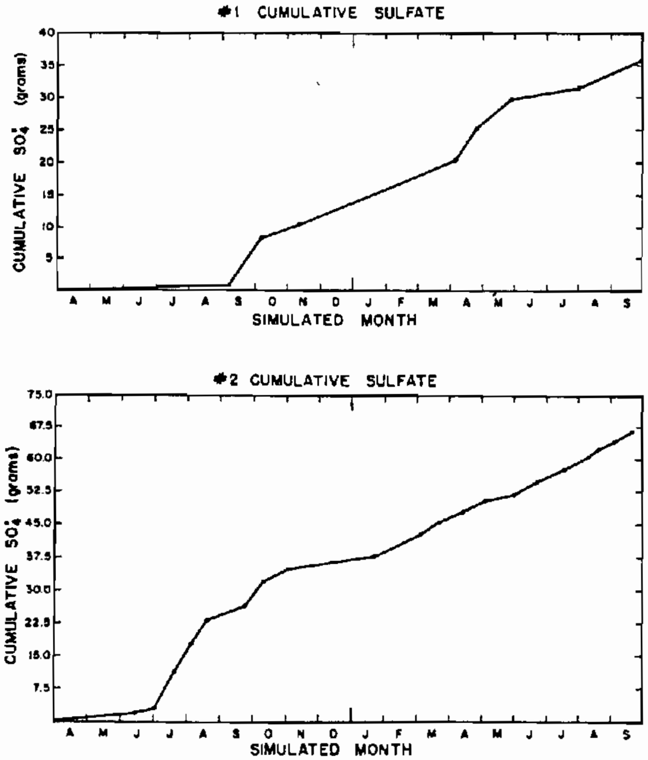
10 CUMULATIVE PHENOL

Fig. 88. Phenol leachate accumulation for four foundries—lysimeter studies.


#1 CUMULATIVE FLUORIDE

#2 CUMULATIVE FLUORIDE

Fig. 89. Fluoride leachate accumulation for four foundries—lysimeter studies.


#1 CUMULATIVE SULFATE

#2 CUMULATIVE SULFATE

Fig. 90. Sulfate leachate accumulation for four foundries—lysimeter studies.

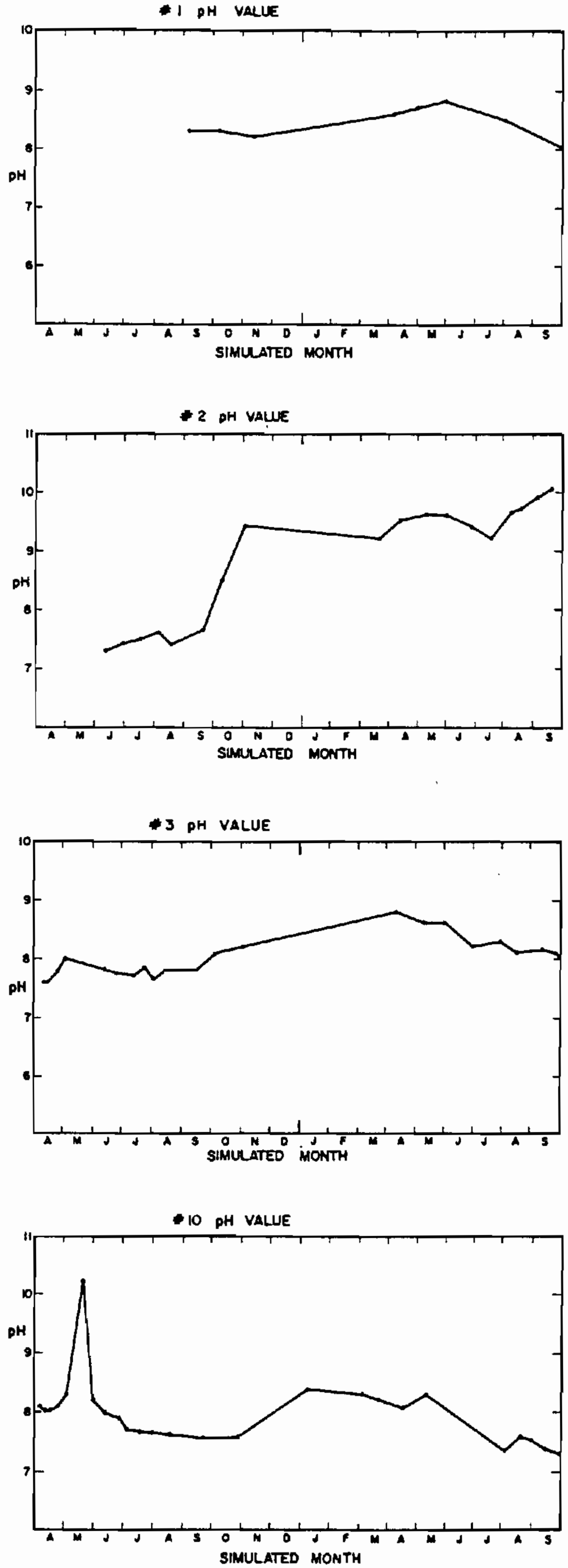


Fig. 91. pH of leachates for four foundries—lysimeter studies.

References

1. T. Kunes, MS Thesis, U. Wis. Madison (Aug 1975).
2. T. Kunes, AFS Paper, 1975 AFS Convention, St. Louis, Missouri.
3. R. W. Heine, P. C. Rosenthal, C. R. Loper, Jr., "Principles of Metal Casting," McGraw-Hill Pub. Co. (1965).
4. C. Santa Maria, R. W. Heine, C. R. Loper Jr., "Foundry Waste to Landfill," AFS Convention Presentation, Cleveland, Ohio (May 1974).
5. C. Santa Maria, "A Study of Foundry Waste Materials," MS Thesis, U. Wis. Madison Library (Jan 1974).
6. N. Nanninga, MS research in progress.
7. I. G. Engels, "Environmental Protection Problems and Their Impact on the Foundry Industry," Report given at the Disamatic Convention of 1973 in Copenhagen, Denmark.
8. P. V. Chernogerov, V. S. Melnikov, "Thermal Degradation of Resin Binders," Russian Castings Production, p 389-390 (1970).
9. Ashland Chemical Co, Laboratory Procedures for Testing Water Leachables from Foundry Sands (1973).
10. Allentown Testing Laboratories, Inc., Testing and Analysis for Lehigh, Inc. (1974).
11. Translations: "Waste Disposal from the Point of View of the Foundry Operator" and "Methods for the Examination and Utilization of Foundry Waste with respect to the Contamination of Terrain and Ground Waters," German references.
12. "Leaching Tests for Solids Developed from Treatment of Industrial Wastes," Chemfix, Division of Environmental Sciences, Inc. Data Sheet 105, Pittsburgh, Pennsylvania.
13. Benedict, McKeown, Hart, "Static Leaching Studies on Pulpwood Bark Residues," ASCE Journal of the Environmental Engineering Division, vol 100, no. EE3 (June 1974).
14. Benedict, McKeown, Hart, "Dynamic Leaching Studies on Pulpwood Bark Residues, ASCE Journal of the Environmental Engineering Division, vol 100, no. EE4 (Aug 1974).
15. Asano, Towlerton, Sanks, "Leaching of Pollutants from Wood-Chip Slurry," ASCE Journal of the Environmental Engineering Division, vol 100, no. EE4 (Aug 1974).
16. O'Conner, Virshbo, Cain, O'Brien, "Regulations Governing Leachates from the Landfill Disposal of Combustion By-Products," presented at ASCE Symposium on Wastewater Effluent Limits, University of Michigan (1973).
17. Standard Methods for Examination of Water and Wastewater, APHA, AWWA, WPCF, 13th ed (1971).
18. Bremner, Keeney, "Steam Distillation Methods for Determination of Ammonium Nitrate and Nitrite," Journal ANAL, CHIM, ACTA, vol 32, p 485-495 (1965).
19. Sawyer, McCarty, Chemistry for Sanitary Engineers, 2nd ed, McGraw-Hill, Inc. (1967).
20. Ludzack, Moore, Ruchhoft, "Determination of Cyanides in Water and Waste Samples," Analytical Chemistry, vol 26, no. 11 (Nov 1954).
21. Munn, "Health Hazards from Isocyanates," Advances in Polyurethane Technology, p 299 (1968).
22. Meddle, Wood, "Determination of Aeromatic Isocyanate in Air," Analyst (London), vol 95, (1129) p 402 (1970).
23. "Disposal of Phenol Containing Sands," Association of Swedish Foundries.
24. D. Hillel, "Soil and Water," in Physical Principles and Processes, Academic Press, New York, p 288 (1971).
25. E. C. Childs, "The Physical Basis of Soil Water Phenomena," John Wiley, New York (1963).
26. C. W. Rose, Agricultural Physics, Pergamon Press, New York, p 226 (1966).
27. J. Bouma, et al, "Soil Absorption of Septic Tank Effluent," University of Wisconsin Extension, Madison, Wisconsin,

Information circular no. 20 (1972).

28. P. Kmet, "Moisture Routing Characteristics of Foundry Wastes," MS Report, University of Wisconsin, Madison, Wisconsin, p 145 (1977).
29. T. H. Liu, "Controlled Environment Degradation Study of Foundry Process Solid Waste," MS Report, University of Wisconsin, Madison, Wisconsin, p 120 (1976).
30. R. K. Ham, R. Karnauskas, "Leachate Production from Milled and Unprocessed Refuse, International Solid Wastes Assoc. Bulletin, no. 14/15, 3-16 (Dec 1974).

Bibliography

American Society of Testing Materials, "Standard Method of Test for Permeability of Granular Soils (Constant Head)," Designation D2434-68 (1968).

"A Quick Reference to the Shell Process," ACME Resin, Technical Data, Forest Park, Ill.

Association of Swedish Foundries, "Disposal of Phenol Containing Sands," (1974).

J. Bouma, "Guide to the Study of Water Movement in Soil Pedons Above the Water Table," 1st ed, Soil Survey Division, USGS, University of Wisconsin Extension, Madison, Wisconsin (1973).

Frevert et al, "Soil and Water Conservation Engineering," John Wiley, New York (1963).

W. Graham, "Reclamation of Chemically Bonded Sands," Foundry Trade Journal, 132, p 677-686 (May 18, 1972).

R. W. Heine, C. R. Loper, C. Santa Maria, N. Nanninga, "Solid Waste from Foundry Processing," Report to AFS, p 33 (1975).

R. W. Heine, J. Pelleg, "Some Effects of Seacoal on White Iron Castings, in Green Sand," AFS Transactions, 72, p 763-768 (1964).

R. W. Heine, C. Wang, R. Green, J. S. Schumacher, "What's the Story on Seacoal Replacements in Foundry Sands," AFS Transactions, 81, p 496 (1973).

B. K. Hough, "Basic Soils Engineering," 2nd ed, Ronald Press, New York, p 513 (1969).

"Leaching Tests for Solids Developed for Treatment of Industrial Wastes," data sheet 105 (1972).

A. D. Morgan, P.H.R.B. Lemon, "High Temperature Properties of Furan Cold Set Resins," Foundry Trade Journal, 134, p 423-432 (Apr 5, 1973).

J. T. O'Connor, M. H. Virshbo, C. J. Cain, C. J. O'Brien, "Regulations Governing Leachates from Landfill Disposal of Combustion By-Products," ASCE National Environmental Engineering Division Conference, Symposium on Wastewater Limits, University of Michigan, Ann Arbor, Michigan (1973).

M. L. Senske, "Solid Waste Management Practices in a Foundry," U.S. HEW (1970).

A. B. Steck, "Thermal Behavior of Molding and Coremaking Material,"Foundry Trade Journal, 130, p 249-253 (Apr 1, 1971).

D. A. Taylor, "CO_2 Process Improvements," Modern Casting, 40, p 125-132 (Sep 1961).

L. E. Wile, "Progress in Coremaking - Shell, Part 1," Foundry Journal (Mar 1970).

BEAK CONSULTANTS INCORPORATED

12072 Main Road
Akron, New York 14001-9755
(716) 542-5544

October 23, 1986

Mr. Keith O'Neill
Wendel Engineers P.C.
7405 Canal Road
Lockport, NY 14094

Reference: Foundary Sand Project #1164

Dear Keith:

Following are the results of the tests performed on the specimen which you dropped off at our office September 18, 1986.

Specimen Submitted

1 Sand Sample

Object

Total Phenolics

Methods

Standards Methods for the Examination of Water and Wastewater,
16th Edition
Colormetric method: distillation for amino antipyriene

Results

Sample (1) 20 micrograms/gram

Sincerely,

William L. Heitzenrater

William L. Heitzenrater
Project Manager
BEAK CONSULTANTS INCORPORATED

WLH/bcl

TESTING OF FOUNDRY SAND

Report Prepared For

DUSSAULT FOUNDRY CORPORATION

By

ADVANCED ENVIRONMENTAL SYSTEMS, INC.

Leonard Borzynski
Technical Evaluation

July 16, 1985
AES Report AXB

ADVANCED ENVIRONMENTAL SYSTEMS, INC.
LABORATORY REPORT

TYPE OF ANALYSIS: WET CHEMISTRY DUPLICATE
UNITS OF MEASURE: MILLIGRAMS/LITER, OR PPM
CLIENT: DUSSAULT FOUNDRY   A.E.S. JOB CODE 01AXB

ANALYSIS	SAMPLE	ORIGINAL CONC.	DUPL. CONC.	AVERAGE CONC.	RANGE	REL. % DIFF.
PHENOLS	1731	.344	.275	.3095	.069	22.39

Relative Percent Difference =
Range/Average X 100

ADVANCED ENVIRONMENTAL SYSTEMS, INC.
LABORATORY REPORT

TYPE OF ANALYSIS: TEST CONTROL WET CHEMISTRY
UNITS OF MEASURE: MILLIGRAMS/LITER, OR PPM
CLIENT: DUSSAULT FOUNDRY A.E.S. JOB CODE 01AXB

ANALYSIS	TYPE	ORIGINAL CONC.	ADDED CONC.	EXPECTED CONC.	REPORTED CONC.	PERCENT RECOVERY	95% CONFIDENCE INTERVAL
PHENOLS	SPIKE	0.31	0.6	0.91	0.53	58.2	N/A

ANALYTICAL METHODOLOGIES REFERENCE LIST

Routine Analyses are Performed in Accordance with Protocols Found in the Following Numbered Sources. These Numbers Correspond to those Listed in the Laboratory Report Under the Reference ("REF") Column.

1 - EPA 600/D-80-021, "Guidelines Establishing Test Procedures for the Analysis of Pollutants; Proposed Regulations", Federal Register 44(233), December 3, 1979.

2 - EPA 600/D-80-022, "Guidelines Establishing Test Procedures for the Analysis of Pollutants; Proposed Regulations, Correction", Federal Register 44(244), December 18, 1979.

3 - EPA 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes", (1983)

4 - EPA 600/4-79-057, "Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater", (1982)

5 - EPA-SW-846, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", second edition (1982)

6 - "Standard Methods for the Examination of Water and Wastewater", 15th Edition, (1980)

7 - New York State Institute of Toxicology Analytical Handbook, October 1982

8 - NIOSH Manual of Analytical Methods, second edition 1977

9 - "The Analysis of Polychlorinated Biphenyls in Transformer Fluid and Waste Oil", EPA Environmental Monitoring and Support Laboratory, draft, June 24, 1980

SCOPE OF WORK

A sample of foundry sand was collected by Mr. James Maxwell and delivered to the AES laboratory on the same day, July 2, 1985.

In order to test the potential for Total Recoverable Phenolics to leach out of the sand, the sample was extracted at pH 5.0 for 24 hours, filtered and analyzed. This Extraction Procedure is specified in EPA SW-846, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, 2nd Edition (1982).

ADVANCED ENVIRONMENTAL SYSTEMS, INC.
LABORATORY REPORT

TYPE OF ANALYSIS: RESULTS - WET CHEMISTRY
UNITS OF MEASURE: MILLIGRAMS/LITER, OR PPM
CLIENT: DUSSAULT FOUNDRY A.E.S. JOB CODE 01AXB

ANALYSIS	METHOD	REF	DETERMINABLE LIMITS	SAMPLE IDENTIFICATION 1731 FOUNDRY SD 07/02/85 EP EXTRACT
PHENOLS	420.1	3	0.1	0.3

Marlene Cheryl Moyer
MARLENE C. MOYER
WET CHEMISTRY DIVISION

693-7154

DUSSAULT FOUNDRY CORPORATION
SOLID WASTE
EP LEACHATE ANALYSES

Report Prepared For Hagio.

DUSSAULT FOUNDRY CORPORATION

by

ADVANCED ENVIRONMENTAL SYSTEMS, INC.

693-7454 → New Cd. → 838-1989

Prepared by:

W. Joseph McDougall

W. Joseph McDougall, Ph.D.
President

February 4, 1981
AES - Report ER

Advanced Environmental Systems, Inc.

Monitoring and Support Laboratory

LABORATORY REPORT

SCOPE OF WORK

Advanced Environmental Systems (AES) has been retained by Dussault Foundry Corporation to perform the necessary waste surveys analyses of waste materials, and complete applications required by all the regulatory agencies including the U.S. Environmental Protection Agency, New York State Department of Environmental Conservation - Region 9 and the Niagara County Health Department.

This report has been prepared in response to Mr. Robert Mitrey's letter to Mr. James Maxwell, dated January 14, 1981 (Appendix A). On January 22, 1981, Mr. Mitrey agreed with Dr. McDougall of AES that it was not appropriate to test for pesticides and herbicides in the EP Toxicity test. Therefore, the leachates have been tested for the eight EP metals and total recoverable phenols.

SAMPLING

On January 22, 1981 Mr. Kenneth Knight of AES collected one grab sample from the sand reclamation dust collector in a one liter glass bottle. The sample was transported directly to the AES laboratory and the extraction procedure was initiated on the same day.

On January 26, 1981, Mr. Kenneth Knight and Dr. Joseph McDougall collected two landfill samples, each composited from five separate surface areas. Also, a grab sample from the sand reclamation dust collector was obtained.

The pertinent weather information was as follows:

Week ending January 24, 1981; 1/21 - 0.4 inches of snow, 1/24 - 0.5 inches of snow. A trace of snow was recorded on 1/19, 1/20, 1/21, 1/23, and 1/25. On Monday, January 26, 1981 when the samples were collected from the waste storage area, the temperature was 42° F. The low temperature for the day was 35° F. and the high was 50° F. The winds were from the south west averaging 17.7 miles per hour and gusting to 45 miles per hour. The ground was very wet.

The samples were transported to the laboratory where Mr. David Szczesny, Laboratory Supervisor, performed all the metals and phenols analyses.

Sample being collected by Ken Knight from north east side of waste pile.

Sample being collected by Ken Knight from north side of waste pile.

Advanced Environmental Systems, Inc.

Monitoring and Support Laboratory

LABORATORY REPORT

METHODOLOGY

One hundred grams of each sample were extracted at pH 5 in accordance with procedures outlined under the EP Toxicity Test procedure, Federal Register, Vol. 45, No. 98, Section 261, Appendix II.

The test methods for analyzing the extract are as follows:

1. For metals: "Methods for Analysis of Water and Wastes", U.S. EPA 600/4-79-020, March 1979, Atomic Absorption Methods.
2. For phenols: Same reference as above, Method 420.1.

LABORATORY REPORT

RESULTS

Table 1. Analysis of EP Extracts for Metals and Phenols
(Expressed as milligrams per liter or ppm)

Analysis	Dust Sand Collector 1/22/81	Landfill #1	Landfill #2	Dust Collector 1/26/81
Arsenic	0.01	<0.01	<0.01	<0.01
Barium	0.30	<0.20	<0.20	<0.20
Cadmium	<0.03	<0.03	<0.03	<0.03
Chromium	<0.10	<0.10	<0.10	<0.10
Lead	<0.25	<0.25	<0.25	<0.25
Mercury	<0.001	<0.001	<0.001	<0.001
Selenium	<0.01	<0.01	<0.01	<0.01
Silver	<0.05	<0.05	<0.05	<0.05
Phenols, Total	0.88	0.66	0.01	1.4

Advanced Environmental Systems, Inc.

Monitoring and Support Laboratory

LABORATORY REPORT

QUALITY ASSURANCE

I. Precision

Analyses for metals were performed in triplicate. The results are an average of the triplicate integrations.

As a check on the precision of the phenol analysis, sample "Landfill #1" was run in duplicate. The results of this analysis are listed in Table 2.

Table 2. Duplicate Analysis of "Landfill #1"
(Expressed as milligrams per liter or ppm)

Analysis	Run 1	Run 2	Average	Range	Critical Range
Phenols	0.659	0.660	0.659	0.001	0.075

LABORATORY REPORT

DISCUSSION

Recovery data are all within the acceptable range for 95% Confidence Limits as recommended by the U.S. EPA, Environmental Monitoring and Support Laboratory.

w York State Department of Environmental Conservation
600 Delaware Avenue, Buffalo, New York 14202

Appendix A

Robert F. Flacke
Commissioner

January 14, 1981

Mr. James Maxwell
Vice President
Dussault Foundry Corporation
21 Washburn Street
Lockport, New York 14094

Dear Mr. Maxwell:

This Department is in receipt of your letter dated December 22, 1980. The schedule and procedures outlined in this letter are in accordance with our previous agreement reached during the meeting of December 16, 1980.

I would also like to advise you that two separate representative samples, for analysis, must be taken from both the dust collector discharge and your previously disposed composite waste located in the northeastern area of your plant. Furthermore, in addition to the parameters listed in Article 261.24 of the May 1980 Federal Register (copy enclosed), you are also requested to analyze for the total recoverable phenolics.

Per your request, I have also enclosed a list of New York State Department of Health approved environmental laboratories with their various analytical capabilities.

Please arrange to submit your leachate potential test results to this Department by February 16, 1981. If you have any questions in regards to any of the above matters, please do not hesitate to contact Mr. Ahmad Tayyebi at 716/842-5041.

Very truly yours,

Robert J. Mitrey

Robert J. Mitrey, P.E.
Associate Sanitary Engineer

RJM:dc

Attachment

WENDEL ENGINEERS, P.C.

7405 Canal Road
Lockport, NY 14094
(716) 433-5993

50 Lakefront Blvd.
Suite 334
Buffalo, NY 14202
(716) 854-5992

LETTER OF TRANSMITTAL

DATE 10/31/86
JOB NO.
ATTENTION
RE:

TO MR. JAMES GOEHRIG
NYSDEC - REGION 9
600 DELAWARE AVE.

WE ARE SENDING YOU ☑ Attached ☐ Under separate cover via ______ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications

☐ Copy of letter ☐ Change order ☐ ______

COPIES	DATE	NO.	DESCRIPTION
3	10/31		DUSSAULT FOUNDRY
			CLOSURE PLAN

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ Approved as submitted ☐ Resubmit ______ copies for approval

☑ For your use ☐ Approved as noted ☐ Submit ______ copies for distribution

☐ As requested ☐ Returned for corrections ☐ Return ______ corrected prints

☐ For review and comment ☐ ______

☐ FOR BIDS DUE ______ 19______ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS PLS RET THE TWO COPIES IN YOUR POSSESSION IF NOT TOO MUCH TROUBLE.

THANKS

COPY TO ______

SIGNED: K. O'Neil

If enclosures are not as noted, kindly notify us at once.