**INTERIM RESULTS: FINES RECYCLE TESTING USING
THE 4-INCH DIAMETER PRIMARY GRAPHITE BURNER**

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Chemical

MASTER

DATE PUBLISHED-MAY 1975

PREPARED FOR THE

UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

IDAHO OPERATIONS OFFICE

UNDER CONTRACT AT (IO-1)-1375 S-72-1

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$2.25

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ICP-1069

Chemical Separations Processes for
Plutonium and Uranium
TID-4500

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by

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ABSTRACT

The results of twenty-two HTGR primary burner runs in which graphite fines were recycled pneumatically to the 4-inch diameter pilot-plant primary fluidized-bed burner are described. The result of the tests showed that zero fines accumulation can easily be achieved while operating at plant equivalent burn rates.

SUMMARY

Fifty-two runs have been made at the Idaho Chemical Processing Plant (ICPP) using the 4-inch diameter primary graphite burner to burn simulated, crushed HTGR fuel blocks. The first thirty runs (Runs 1 through 30) were made without fines recycle (Reference 1). Runs 31 through 52 were made using a pneumatic fines recycle system.

The first 15 runs (31 through 45) using pneumatic fines recycle were made to determine the effects of fluidizing velocity, feed rate, bed temperature, and bed depth on fines burning rate, and oxygen utilization. The results of the 15 tests showed that to maximize the fines burning rate and oxygen utilization (1) the fluidizing velocity should be as low as required graphite burning rates will allow, (2) the feed rate should be controlled such that just enough graphite is present in the bed to use the available oxygen (excess feed graphite will unnecessarily increase the fines generation rate), and (3) the bed temperature should be maintained as high as burner construction material will allow to maximize reaction rates. Bed depth does not appreciably affect combustion efficiency, but does affect the available heat transfer area. Graphite burning rates higher than 25 kgC/hr-ft² were not realized during this first series of runs due to fines bridging in the filter chamber and in the fines recycle hoppers. However, pneumatic fines recycle was successful at 25 kgC/hr-ft² burn rates. The primary burner system was modified to eliminate the fines bridging problems.

Six subsequent runs (Runs 46 through 51) were made to test the effect of fines injection technique at a fluidized-bed L/D ratio of 7.5 and fines burning at the plant equivalent burn rate of 35 kgC/hr-ft².

The results of the six tests showed that: (1) fines entry at a location 5/16 inches above the distributor plate is more effective for fines burning than fines entry 3 inches above the plate, (2) a tangential fines inlet provides no better burning of fines than a radial entry, and (3) operating at a fluidized-bed L/D ratio of 7.5 does not increase fines burning rates relative to those obtained when burning at an L/D ratio of 4.

All runs using pneumatic fines recycle (Runs 31 through 51) were less than five hours duration. A long-term (27 hour) run (Run 52) was then made to demonstrate fines burning and equipment performance at equivalent demonstration plant operating conditions. More fines were burned than generated during the 27-hour run. Equipment operation was generally troublefree; however, some minor feed bridging and fines plugging occurred.

Based on the results of the experimental testing, pneumatic fines recycle is a practical method for burning graphite fines. Semi-continuous operation can produce product containing less than 2% exposed combustible graphite.

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INTERIM RESULTS: FINES RECYCLE TESTING USING THE
FOUR-INCH DIAMETER PRIMARY GRAPHITE BURNER

I. INTRODUCTION

Proposed reprocessing of Ft. St. Vrain fuel is based on whole block crushing to minus 3/16-inch size by a series of three crushers. The crushed material will be burned in a primary fluidized-bed burner. The exposed fissile and fertile particles will be separated, crushed, burned, and leached for recovery of uranium and thorium.

Ideally, the primary burner should burn all the matrix graphite from the fissile and fertile particles. However, whole block crushing generates significant quantities of graphite fines; fines are also generated during burning of the larger graphite pieces. Graphite fines are very light and elutriate rapidly from the fluidized bed before and during burning.

Four different methods were considered for burning the graphite fines: (1) in-vessel filters in the primary burner, (2) fines burning in the secondary burner, (3) a separate fines burner, and (4) external fines recycle to the primary burner. The use of in-vessel filters in the primary burner failed due to inefficient fines recycle from the filters to the bed and due to fines burning in the vapor space which caused the filters to burn through. Fines burning in the secondary burner was abandoned because the added graphite volume significantly increased the potential for burn through of the in-vessel filters of the secondary burner. A separate burner devoted to fines burning was considered only as a last resort. The simplest and most promising method of fines burning was fines recycle to the primary burner. Two methods were used to feed fines into the primary burner bed: (1) augering and (2) pneumatic injection. Auger systems are plagued with mechanical alignment, fines bridging, and high temperature operation problems which would probably make them unacceptable for operation in the demonstration plant. Pneumatic injection requires no moving parts and is not significantly affected by alignment or high temperatures. Continuous pneumatic recycle of unburned graphite fines from a collection hopper to the primary burner appears to be the most satisfactory method for burning the fines.

II. EQUIPMENT AND PROCEDURES

Flow diagrams of the 4-inch diameter primary graphite burner are shown in Figures 1 and 2. The equipment used for the fines recycle parametric studies (Runs 31 through 45) is shown in Figure 1. The system consisted of a feed pot and variable-speed auger to meter fresh feed to the burner, a 4-inch diameter burner vessel, an 8-inch diameter filter pot containing two sintered-metal filters, and a double-pot fines recycle system. The nozzle for injecting fines into the burner was a horizontal, 1/4-inch diameter pipe located 3 inches above the distributor. The filters were 2-3/4 inch O.D., 18 inches long, and 5 micron porosity. All metal parts were made from 304 or 304-L stainless steel, except the filters, which were 316-L stainless steel and the distributor plate, which was Hastelloy C-276.

The equipment used for the fines injection studies (Runs 46 through 52) is shown in Figure 2. The pilot-plant unit was modified following the 15 parametric runs to include an off-gas cyclone upstream of the filter pot. The filter pot outlet pipe size was increased from 1 inch to 1-1/2 inches diameter, and a 28-inch spool-piece (4-inch diameter) was added to increase the burner height. In addition, two new fines inlets were installed 5/16 inches above the distributor plate. One entered the burner tangentially and the other radially. The sintered metal filters were replaced with new ones of the same dimensions, but having a 10 micron porosity.

The equipment used during the 27-hour run (Run 52) was identical to that used in Runs 46 through 51, except that actuators were installed on the valves associated with the two fines recycle hoppers. The actuators allowed recycle fines to be switched from one hopper to the other either manually or automatically.

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Figure 1. Schematic Diagram of Pilot-Plant Primary Burner used for Fines Recycle Parametric Studies (Runs 31 through 45) ACC - A - 1751

Figure 2. Schematic Diagram of Pilot-Plant Primary Burner Used for Fines Injection Technique Studies (Runs 46 through 52)

Process Description

The crushed feed simulated, as nearly as possible, that anticipated for the demonstration plant: minus 3/16-inch particle size, 23.5 wt% crushed fuel rods, and 76.5 wt% graphite. The feed particle size distribution is shown graphically in Figure 3. Also shown in Figure 3 is the feed size distribution used during General Atomic's 4-inch diameter primary burner Run 38. This particular feed was crushed from a half-length loaded fuel block. The particle size distribution should be very representative of what will occur in the demonstration plant.

The feed was metered to the burner by a variable speed auger. The bed was fluidized by 100% oxygen, and the fines recycle gas (0.2 to 0.5 scfm) was air. The off-gas from the burner flowed through the external filter chamber, through a HEPA filter, and to the atmosphere.

The fine graphite particles elutriated from the bed were collected on the surface of the sintered metal filters and periodically displaced from the filter surface by a pulsed blowback system. The pulse duration was approximately 0.1 second. The time between pulses to each filter was varied from 1 to 10 minutes. No significant change could be seen on the 0-10 psi filter ΔP scale. The displaced fines fell by gravity into one of the two fines recycle hoppers which were alternately pressurized with air to allow feeding the collected fines into the fluidized bed.

The fines recycle hoppers contained an inventory of fines (2500 to 3800 grams) at the start of each run. This allowed fines feeding during the entire run and rapid simulation of steady-state conditions; the need for operating the burner two or three hours to generate a fines inventory was thus unnecessary.

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Figure 3. Fresh Feed Particle Size Distributions

Burner Startup and Supplemental Heating Method

Burner startup and supplemental heat was provided by a CO/O₂ combustion torch located in the wall of the fluidized-bed burner. The startup procedure used for all of the runs was to start the fluidizing air at 1 ft/sec fluidizing velocity. This velocity was maintained during the startup phase by decreasing the fluidizing gas flow rate as the bed temperature increased. A bed (2500 to 6000 grams) of fissile and fertile particles from the previous run was then charged to the burner by gravity. The torch was ignited and the bed heated to 600°C. When the 600°C bed temperature was reached, the fluidizing gas was switched from air to 100% O₂, the feed auger was activated, and the auger speed adjusted to the feed rate specified for the run. When the bed temperature exceeded 800°C and significant graphite combustion occurred, the torch was deactivated. When the burner reached the specified operating temperature, the fluidizing oxygen rate was adjusted to the rate specified for the run, and fines recycle was initiated. Stable conditions were usually attained within ten minutes after reaching operating temperature.

During steady-state operation, the bed temperature was normally controlled by adjusting the fines recycle rate (increasing the fines recycle rate cooled the bed). Cooling air through the burner shroud was required when fines were not being recycled at a sufficient rate to cool the burner.

During Runs 31 through 51, steady-state conditions were maintained while a total of 8000 grams of feed was metered to the burner (except during those cases when equipment failure forced an early shutdown). During the 27-hour run (Run 52) the burner was operated semi-continuously; at 2.5-hour intervals, the feed to the burner was stopped and the graphite was allowed to burn from the bed. When the oxygen concentration in the off-gas exceeded 3% (indicating the bulk of the graphite was burned), approximately 1600 grams of product was drained by gravity from the bed.

After the feed supply was exhausted, the graphite was allowed to burn from the bed and the run ended when there was no longer enough graphite in the bed to maintain the burner temperature.

III. EXPERIMENTAL FINES RECYCLE TESTING

A summary of the operating conditions for all twenty-two fines recycle runs is given in Table I. The first fifteen runs (Runs 31 through 45) were made to test the effect of fluidizing velocity, feed rate, bed temperature, and bed depth on fines burning rate, oxygen utilization, and general primary burner operability while recycling fines. A two-level, fractional factorial design was chosen to maximize the amount of data obtained from the eight planned runs. The original run plan called for the high-level fluidizing velocity to be 2.5 ft/sec (corresponding to a burn rate of 35 kg C/hr-ft²). Five runs (Runs 31, 32, 36, 37, 39) were attempted at this burn rate, but the off-gas system was not designed for the resultant high fines loading. Fines bridging and plugging in the filter chamber invalidated the recycle data at the 35 kg C/hr-ft² burn rate. The high-level fluidizing velocity was lowered to 1.8 ft/sec (corresponding to 25 kg C/hr-ft²), and four runs (41, 43, 44, 45) were made with few fines bridging problems. The low-level fluidizing velocity was 1.0 ft/sec. Run 42 was made with fines recycle only (no feed) with the CO torch providing the process heat.

Specified values of the independent variables during the 15 parametric runs were: graphite feed rates of 100 and 200% of the stoichiometric rate based on the fluidizing oxygen flow rate, bed temperatures of 875 and 900°C, and starting bed weights of 2500 and 4000 grams of fissile and fertile particles. Even though the same amount of feed graphite was metered to the burner in each completed run, the run time varied because of different oxygen fluidizing rates and because different amounts of fines were burned during each run.

TABLE I
SUMMARY OF OPERATING CONDITIONS FOR FINES RECYCLE TESTING
IN THE FOUR-INCH DIAMETER PRIMARY GRAPHITE BURNER

Run No.	Maximum Burning Rate, kg C/hr-ft ²	Oxygen Fluidization Velocity, ft/sec	Feed Rate, grams/min	Stoichiometric Feed Rate, %	Average Bed Temp., °C	Starting Bed Weight, grams	Starting Fines Inventory, grams	Fines Entry Location (a)	Type of Entry (b)
31	35	2.6	125	200	900	4000	3000	3	R
32	35	2.6	125	200	900	4000	3000	3	R
33	15	1.0	27	100	875	2500	3000	3	R
34	15	1.0	27	100	875	2500	3000	3	R
35	15	1.0	54	200	875	4000	3000	3	R
36	35	2.6	62	100	900	2500	3000	3	R
37	35	2.6	62	100	875	4000	3000	3	R
38	15	1.0	27	100	900	4000	3000	3	R
39	35	2.6	125	200	875	2500	3000	3	R
40	15	1.0	54	200	900	2500	3000	3	R
41	25	1.8	45	100	900	2500	3000	3	R
42	15	1.0	0	0	900	4000	3000	3	R
43	25	1.8	89	200	900	4000	3000	3	R
44	25	1.8	45	100	875	4000	3000	3	R
45	25	1.8	89	200	875	2500	3000	3	R
46	35	2.6	62	100	900	3111	2500	3	R
47	35	2.6	62	100	900	3808	2500	5/16	R
48	35	2.6	62	100	900	4000	3000	5/16	T
49	35	2.6	62	100	900	4000	3000	5/16	R
50	35	2.6	62	100	900	4000	3000	5/16	R
51	35	2.6	62	100	900	6000	3000	5/16	R
52	35	2.6	62	100	900	4500	3800	5/16	R

- (a) Distance above distributor plate in inches
(b) T = Tangential entry,
R = Radial Entry

Following the 15 parametric runs, six runs (Runs 46 through 51) were made to test the effect of fines injection technique and a fluidized-bed L/D ratio of 7.5 on fines burning at combustion rates of 35 kg C/hr-ft². The burning rate (35 kg C/hr-ft²), the fluidizing velocity (2.5 ft/sec), the feed rate (62 g/min), and the average bed temperature (900°C) were identical for all the runs. The starting bed weight was not the same for all the runs, but it had previously been shown that the bed weight (bed height) has little or no effect on rate of fines burning. The starting fines inventory was either 2500 or 3000 grams for all the runs. Three different fines entries were tested; the first entry tested was radial at a point 3 inches above the distributor plate. The second was a tangential entry 5/16 inches above the plate, and the third was a radial entry 5/16 inches above the plate.

The final run (Run 52) was made to test pneumatic fines recycle and general equipment operation during an extended time period. Although previous runs had been made at simulated demonstration plant conditions, none had exceeded a five-hour time period. Additional data were needed to evaluate equipment reliability and steady-state fines inventories.

The conditions were the same as for the previous six runs except the startup bed was 4500 grams of fissile and fertile particles, the starting fines inventory was 3800 grams, and the fines recycle used a radial entry 5/16 inches above the distributor plate.

IV. RESULTS

A summary of results for the 22 fines recycle runs is shown in Table II. Results of the 15 parametric tests, the 6 fines injection tests, and the extended run are reported in the following text.

Results of 15 Parametric Runs (Runs 31 through 45)

The primary burner equipment, instrumentation, and CO torch performed satisfactorily during the fines recycle runs. The filter chamber and the fines recycle hoppers, however, caused continual fines bridging at burning rates of 35 kg C/hr-ft² during the initial series of runs. The fines bridging was due to the lack of an off-gas cyclone to remove the bulk of the entrained fines from the off-gas before they reached the filter pot and a small (1-inch diameter) outlet line at the bottom of the filter pot. However, the fines system worked acceptably well at burn rates of 15 and 25 kg C/hr-ft², because of the reduced fines loading in the off-gas. No filter plugging or filter burning was experienced. The filter ΔP varied from 0.4 to 2.0 psi depending on the fluidizing gas rate. The filters reached temperatures as high as 550°C during fines recycling, but no filter damage was visible.

Corrosion coupons contained in the burner bed and vapor space during the 15 runs were removed from the burner and are being analyzed for carburization attack. Visually, the coupons in the vapor space were pitted much worse than the coupons located in the bed.

The amount of graphite (feed and fines) burned during the 15 runs is shown as a function of the high and low levels for each controlled variable in Figures 4 and 5.

TABLE II

SUMMARY OF RUN RESULTS FOR FINES RECYCLE TESTING IN THE
FOUR-INCH DIAMETER PRIMARY GRAPHITE BURNER

Run No.	Final Bed Weight, grams	Final Fines Weight, grams	Combustibles In Bed, wt%	Combustibles In Fines, wt%	Total Graphite Burned, grams	Average Off-Gas Concentration			Average Filter ΔP , psi	Run Time, min	Comments
						O ₂ , %	CO ₂ , %	CO, %			
31 ^(B)	5011	4500	(A)	(A)	5190	6	83	2	2.0	103	Fines bridged in filter pot
32 ^(B)	5160	4531	0.9	92.5	5159	4	82	3	1.6	118	Fines bridged in filter pot
33 ^(C)	--	--	--	--	--	--	--	--	--	--	Early shutdown - fines plug
34	3846	3097	(A)	(A)	6593	5	58	8	0.5	302	Completed run - no fines bridging
35	5260	4322	1.8	93.9	5368	2	63	9	0.6	203	Completed run - no fines bridging
36 ^(B)	3756	4350	(A)	(A)	5340	12	60	4	2.0	136	Fines bridged in filter pot
37 ^(C)	--	--	--	--	--	--	--	--	--	--	Early shutdown - fines plug
38	5064	2064	0.3	90.3	7626	3	60	5	0.7	306	Completed run - no fines plug
39 ^(C)	--	--	--	--	--	--	--	--	--	--	Early shutdown - fines plug
40	3668	3788	(A)	(A)	5902	3	60	8	0.5	215	Completed run - no fines bridging
41	3787	3001	0.2	90.3	6689	4	62	7	1.3	199	Completed run - no fines bridging
42	3998	2217	(A)	(A)	783	30	45	4	2.0	85	Completed run ~ 11 kg of fines fed - CO torch supplied
43	4987	4050	0.1	90.6	5640	3	66	8	1.4	148	Completed runs - no fines bridging ~ 50% of process heat
44	5202	3751	1.5	90.7	5939	9	58	3	2.0	177	Completed run - no fines bridging
45	3600	4377	2.5	89.3	5313	4	60	4	1.7	147	Completed run - no fines bridging
46	3808	2589	(A)	(A)	4171	0.5	67	25	0.7	112	Rubber gasket melted in fines recycle system
47	3835	2835	(A)	(A)	1178	4	64	(A)	0.7	29	Early shutdown - glass fines recycle hopper broke
48	4829	2257	(A)	(A)	7433	0.5	66	14	0.8	141	Completed run - no problems
49	4203	1850	(A)	(A)	6143	0.5	68	14	0.8	61	Early shutdown - Feed system bridged - could not be cleared
50	5696	2229	0.1	72.9	7461	0.5	63	16	0.8	138	Completed run - no problems
51	7249	2228	0.2	70.4	7462	1	69	16	0.8	147	Completed run - no problems
52	3890	1352	0.2	68.7	73,717	1	68	15	1.0	1600	

(A) Data not taken.

(B) Fines bridging occurred in recycle system making the graphite burning data invalid.

(C) Run not completed.

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Figure 4. The Trend of Effect of Controlled Variables on Graphite Burning

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Figure 5. The Relative Effect of Controlled Variables on Graphite Burning

The ordinates in Figures 4 and 5, labeled "Total Graphite Burned", were calculated using the formula

$$TGB = FMTB \times 0.836 + IFI - FFI.$$

Where : TGB - Total graphite burned

FMTB - Feed metered to burner

0.836 - Fraction of feed which is graphite and
carbon external to the SiC hull.

IFI - Initial fines inventory

FFI - Final fines inventory

Although the total graphite burned does not directly determine the quantity of fines burned, the same amount of feed (8 kg) was used in each run. The difference in total graphite burned from run to run is a relative measure of the difference in the amount of fines burned.

The oxygen utilization (obtained from the off-gas analyses and defined as the $(CO + CO_2) \times 100 / (CO + CO_2 + O_2)$ ratio) is shown as a function of the controlled variables in Figures 6 and 7.

The weight percent combustibles remaining in the bed at the end of the runs was an average of about 1% and a maximum of 2.5% for the runs for which the data were taken. No extra heat was added to the bed at the end of the runs to achieve these low values. The average amount of noncombustible material remaining in the fines was 9 wt%. This material consisted of uranium oxide, thorium oxide, and silicon carbide hulls from broken particles. No whole particles were found in the fines.

Run 42 was made with the CO torch supplying the process heat to burn fines to test whether or not it was practical to dispose of the fines during a period of the run separate from the main burning period. No feed was introduced to the burner during the run; fines were continually recycled batchwise through the bed pneumatically. The bed was fluidized with oxygen at 1.0 ft/sec. The run started with an inventory of 3000 grams of fines, and after 5 cycles through the burner, approximately 25% of the fines had been burned. The only problem encountered during the run was fines burning in the vapor space due to the high oxygen concentration ($\sim 30\%$) in the off gas. Even though the fines recycle rate was 1 kg/minute or higher, not enough graphite was in the bed to reduce the oxygen concentration to a low enough level to extinguish the above bed burning.

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Figure 6. The Trend of Effect of Controlled Variables on Oxygen Utilization

Figure 7. The Relative Effect of Controlled Variables on Oxygen Utilization

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Results of Fines Injection Runs (Runs 46 through 51)

The results of the six fines injection runs demonstrated that the addition of a cyclone and related modifications were successful in eliminating fines bridging in the filter pot and piping at burn rates of 35 kg C/hr-ft² and a fluidized bed L/D ratio of 4. Operation was also successful with a fluidized-bed L/D ratio of 7.5; severe plugging or excessive fines carryover was not detected in the 4-inch diameter burner.

Three of the six fines recycle runs (Runs 48, 50, and 51) were entirely successful; three other runs (Runs 46, 47, and 49) resulted in successful fines burning, but the runs were terminated prematurely due to melting of a gasket, cracking of a glass fines pot, and bridging in a fresh feed line. These deficiencies were subsequently corrected. During the three successful runs, no plugging of fines or feed lines occurred, and more fines were burned than generated. The equipment operated satisfactorily and the temperature was controlled between 880 and 920°C by varying the fines recycle rate. The fines system became very hot and a rubber gasket sealing the fines recycle hopper melted when Run 46 was 2/3 completed. All rubber gaskets in the fines systems were replaced with high temperature material prior to Run 47. When Run 47 was 1/4 complete, one of the two glass fines recycle hoppers cracked; the glass pots were replaced with stainless steel pots for the remaining runs.

The fresh feed addition line to the burner was quite small (1" diameter) and occasionally bridged. The bridges could normally be cleared easily, but the bridge formed during Run 49 could not be cleared, and the run was terminated when 3/4 completed.

The pneumatic fines recycle system worked very well (except for the gasket and glass problems) during all six runs. No bridging or plugging was experienced, and only 0.5 scfm air was required to transport 1 kg of fines per minute into the burner.

Results of 27-Hour Run (Run 52)

During the 27-hour run, the bed temperature was controlled between 880 and 920°C, except for the brief periods when feed bridging occurred. The burner instrumentation, filter blowback system, off-gas analyzers, and automatic fines hopper switching system all performed with no problems. Occasional fines plugging and feed bridging during product discharging were the only significant problems during the run. No fines plugging whatsoever was detected during previous short-term runs (Runs 46 through 51), but when the valve actuators were installed on the

fines-hopper outlet valves, a pipe nipple and coupling (about 4 inches in total length) were added to the fines outlet line to provide enough room for the actuator. About every tenth time, the fines pots were switched, a slight plug would form in one of the nipple-coupling sections and momentarily interrupt the fines flow. The plug either immediately cleared itself or was easily cleared by back pressuring the line. The plugs were mostly an inconvenience, because they tended to upset the burner temperature control. The nipple and coupling sections were subsequently removed to minimize the potential for any further fines plugging.

The fresh feed to the burner entered the vessel below the bed level when more than 4000 grams of bed were fluidized. As long as the feed auger was operating, the feed system worked properly. When the feed was stopped to burn the graphite from the bed, the bed apparently stagnated in the feed line and either bridged and/or sintered enough to prevent feed from entering the bed when the auger was subsequently activated. Since it sometimes required several minutes to restart feed flowing through the feed line after a product batch was discharged, the CO torch had to be used to maintain the bed above 800°C. The torch performed reliably each time it was needed. After the feed bridging problem was encountered early in the run, the bed weight was maintained at or below 4000 grams in an attempt to prevent further feed bridging.

The weight of the fines inventory decreased steadily during the run. Initially, the fines were 90% combustible; the final fines were 69% combustible. The inert material in the fines consisted of particle hulls, thorium oxide, and uranium oxide. It is assumed that had the run continued, the total fines weight would have reached a minimum, and then begun to increase slowly. The increase would be due to accumulation of non-combustible material from broken particles collecting in the fines more rapidly than the graphite remaining in the fines burned. At some point in time, part or all of the fines would have to be transferred to the secondary burner for subsequent processing.

The O_2 and CO_2 concentrations in the off-gas were steady during the run, except during blowback when air was injected into the system. The average concentrations were: 1% oxygen (due to air purges located downstream of the burner) and 68% carbon dioxide. The carbon monoxide concentrations ranged from 5 to 20% in the off gas depending on the fines recycle rate. When the fines recycle rate was high, the CO concentration was also high, and when the recycle rate was decreased, the CO concentration decreased.

The pressure drop across the sintered-metal filters remained constant at 30 inches water gauge throughout the run. The filter temperature ranged from 150 to 250°C.

During the 27 hours of semi-continuous operation, nine product batches and the final bed were discharged from the burner. The weight of each product batch and the concentration of combustibles in the product are given in Table III. The semi-continuous mode of operation was satisfactory, except for the feed bridging discussed earlier. The combustible material in the product batches ranged from 0.13 to 1.86 weight percent. No supplementary heating was required to consistently achieve less than 2% combustibles in the burner product.

TABLE III
COMBUSTIBLE CONTENT OF PRODUCT FROM 27-HOUR RUN

<u>Product Batch</u> <u>No.</u>	<u>Weight,</u> <u>grams</u>	<u>Combustibles,</u> <u>wt%</u>
1	1311	1.86
2	1625	0.44
3	1569	1.30
4	1627	0.45
5	1631	0.30
6	1591	0.56
7	1594	0.13
8	1781	0.72
9	1602	0.31
Final Bed	3890	0.15
Average		0.62

V. DISCUSSION OF RESULTS

The most important result of all the fines recycle tests is that a zero fines accumulation rate can easily be achieved in the primary burner by continuous pneumatic fines recycle. The graphite burning results given in Figure 4 show that the fines burning rate increased with bed temperature, was not appreciably affected by bed weight, and decreased as the fluidizing velocity or feed rate was increased. The feed rate and fluidizing velocity were perturbed approximately 100%, and the bed temperature was perturbed only about 2%. However, approximately the same increase or decrease in the amount of graphite burned was noted. This result is shown more clearly in Figure 5 which has the independent variables plotted as percent change instead of the high and low condition. The figure plainly shows that graphite burning is much more sensitive to bed temperature than to any of the other variables. This indicates that for most efficient fines burning the primary burner should be operated at as high a bed temperature as material codes will allow.

Much the same result with respect to oxygen utilization is shown in Figure 6. However, an increase in feed rate increased the oxygen utilization while decreasing the amount of fines burned. The bed temperature, again, had a much greater effect on oxygen utilization than any of the other variables, as shown in Figure 7.

The severe pitting of the corrosion coupons in the vapor space during the 15 parametric runs apparently was caused by fines burning in the vapor space during process upsets which allowed excess oxygen to reach the vapor space. When fines burning occurred above the bed, the vapor space temperatures sometimes exceeded 1000°C. Nitrogen was added to the vapor space gas to quench the reaction. A cooling shroud around the vapor space would be very effective in controlling this problem since the off-gas could be cooled rapidly to prevent burner wall overheating.

During Run 46, the fines were injected radially, 3 inches above the distributor plate. Although the run was not completed, the fines recycle data were valid for the run conditions. The run started with 2500 grams of fines and ended with 2589 grams.

Very nearly as many fines were burned as generated, even with the fines being injected at a location relatively high above the distributor. Run 48 was made at the same conditions as Run 46, except the fines inlet was 5/16 inches above the plate and entered tangentially. The run began with 3000 grams of fines and ended with 2257 grams. Considerably more fines were burned than generated.

Run 50 was made under exactly the same conditions as Run 48, except the fines entered the bed radially at a location 5/16 inches above the distributor plate. The run began with 3000 grams of fines and ended with 2229 grams. Slightly more fines were burned with the radial entry than with the tangential entry. The difference of 28 grams of fines is not significant, and the tangential entry offers no apparent advantage over radial entry for fines burning. However, better temperature control, a smaller axial temperature gradient through the bed, and less thermal cycling was achieved with the radial inlet.

Run 51 was made at the same operating conditions and type of entry used in Run 50, but a 6000 gram starting bed was used in Run 51. The final fines weight in Run 51 was 2228 grams, which is essentially the same as realized for Run 50.

Run 49, although not complete, had only 1850 grams of fines remaining at shutdown. This is significantly less than in any of the completed runs. Severe above-bed burning was experienced in Run 49 during the time the feed was bridged in the feed line. Apparently, the above-bed burning consumed 400 to 600 grams more fines than normally would have been burned during a run of that length.

Run 52 demonstrated that the primary burner can achieve a zero fines accumulation rate during a long-term run while operating at a burning rate of 35 kg C/hr-ft^2 . The semicontinuous mode of operation consistently produced a product which contained less than 2 wt% combustible material with little or no decrease in the net burner throughput.

VI. CONCLUSIONS AND FUTURE EXPERIMENTS

Conclusions based on fines recycle tests are:

- (1) The primary burner is capable of burning more fines than are generated when operated at a burning rate of 35 kgC/hr-ft^2 .
- (2) The semi-continuous operating mode will consistently produce product with less than 2% combustibles with no supplementary heating and without significantly decreasing the burner throughput.
- (3) The bed temperature must be maintained as high as material codes and safety will allow to maximize the fines burning rate and oxygen utilization.
- (4) Fines burning in the vapor space when the oxygen level rises in the off-gas during burner upsets or during the "burnout" period at the end of a cycle is potentially a very serious problem, since the vapor-space burner wall or vessel internals (thermowells, etc.) could be overheated.
- (5) The fines inlet 5/16 inches above the distributor plate resulted in a greater fines burning rate than the inlet 3 inches above the plate.
- (6) A tangential fines inlet offers no advantage for fines burning over the radial entry.
- (7) Bed depth does not have a significant effect on fines burning or oxygen utilization.
- (8) The feed rate should be controlled so that there is just enough graphite surface area in the bed to consume all of the fluidizing oxygen. Feed graphite in excess of this amount will compete for O_2 and decrease the fines burning rate.
- (9) The oxygen fluidizing velocity in the primary burner should be kept as low as the required rate of graphite burning will allow. Additional gases fed into the bed for purges, quenching, or fines transport must be minimized to increase fines retention in the bed.
- (10) A fluidized-bed L/D ratio of 7.5 causes no excessive slugging or fines carryover in the 4-inch diameter burner, does not increase fines burning, but does increase the available bed-to-wall heat transfer area.

Future experiments will be based on the following:

1. The burner will be modified to eliminate any further fines plugging and feed bridging.
2. A perforated, conical distributor plate will be incorporated in the testing.
3. A rotary valve will be tested as an air lock device in the fines recycle system to possibly eliminate the need for the double fines pots.

VII. REFERENCES

1. W. B. Palmer, "Interim Results: Primary Burner Testing without Fines Recycle", ERDA Report ICP-1068 (May 1975).

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