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**PROCESS DEVELOPMENT REPORT —
0.20-m SECONDARY BURNER SYSTEM**

by
W. S. RICKMAN

**Prepared under
Contract EY-76-03-0167
Project Agreement No. 53
for the San Francisco Operations Office
U.S. Energy Research and Development Administration**

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ABSTRACT

HTGR fuel reprocessing consists of crushing the spent fuel elements to a size suitable for burning in a fluidized bed to remove excess graphite; separating, crushing, and reburning the fuel particles to remove the remainder of the burnable carbon; dissolution and separation of the particles from insoluble materials; and solvent extraction separation of the dissolved uranium and thorium.

Burning the crushed fuel particles is accomplished in a secondary burner. This is a batch fluidized-bed reactor with in-vessel, off-gas filtration. Process heat is provided by an induction heater.

This report documents operational tests performed on a commercial size 0.20-m secondary burner using crushed Fort St. Vrain type TRISO fuel particles. Analysis of a parametric study of burner process variables led to recommending lower bed superficial velocity (0.8 m/s), lower ignition temperature (600°C), lower fluid bed operating temperature (850°C), lower filter blowback frequency (1 cycle/minute), and a lower fluid bed superficial velocity during final bed burnout (0.45 m/s).

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1. INTRODUCTION

The HTGR fuel reprocessing flowsheets for Fort St. Vrain and large reactors are shown in Figs. 1-1 and 1-2. They both entail crushing the fuel element, burning the crushed element, and separating the resultant burner product into fissile and fertile particle streams.

Those particle streams containing TRISO-coated particles (see Fig. 1-3) are then further crushed to expose the carbide kernel and inner carbon coatings. This crushed particle stream is then oxidized in a secondary burner to yield a heavy metal oxide and SiC shell mixture, which is in turn leached to isolate the heavy metals.

The secondary burner is a batch fluidized-bed reactor with a flat perforated inlet gas distributor plate and in-vessel off-gas filters. Process heating is supplied by an induction heater while cooling is accomplished by air flow through annular cooling jackets. Crushed particle feed is supplied by a gravity-pneumatic feeder at the upper end of the vessel. Product is removed through a valve port just above the distributor plate; it is then pneumatically transported to the next process step.

A fluidized-bed reactor is being used because of its good heat transfer properties. It also serves as an excellent containment for the dusty feed material.

The distributor plate allows good fluidization characteristics (as seen from an even bed temperature profile) and interfaces well with the product removal valve and pneumatic product transport system. Sintered metal cylindrical filters separate the off-gas from entrained bed material. They are cleaned using a reverse jet blowback technique.

Fig. 1-1. Simplified HTGR head end flow diagram (TRISO-TRISO fuel)

Fig. 1-2. Simplified TRISO-BISO reprocessing flow diagram

<u>MICRONS</u>	<u>FISSILE</u>	<u>FERTILE</u>
KERNEL DIAMETER	175-240	380-450
BUFFER THICKNESS	55	60
INNER DENSE COATING THICKNESS	25	30
SiC THICKNESS	25	25
OUTER DENSE COATING THICKNESS	35	50

Fig. 1-3. Fort St. Vrain TRISO coated fissile and fertile particles

The burning cycle is as follows:

1. Feed crushed particle batch and induction heat to 600°C. Use an inert gas flow for fluidization.
2. Ignite by gradually increasing the gas flow to 2.6 ft/sec of pure O₂. External heating and cooling are on demand to keep the bed at 850°C during the run.
3. Low bed carbon is detected by measuring the off-gas CO level; when it falls below 2%, the inlet gas is changed to 60% O₂ and the flow rate is gradually reduced to allow fine carbon to reenter the bed for combustion.
4. When the burning rate decreases to a preset value, fluidize the bed with pure CO₂ and cool to 500°C.
5. Pneumatically transport the product to a storage bunker.

Development work on the secondary burner unit operation was performed on a 0.10-m diameter burner. An overall view of the burner vessel, illustrating the key features just discussed, is shown in Fig. 1-4.

A 0.20-m diameter burner was then designed, fabricated and installed. An overall cross section is shown in Fig. 1-5; the installed burner system is shown in Fig. 1-6. This burner is the size specified for a commercial fuel reprocessing plant. It can process the TRISO fuel particles contained in 16 LHTGR fuel elements during each 5-hour batch burning cycle.

This report describes the first year of testing performed on the 0.20-m secondary burner. It includes a detailed description of each of the nine burner cycles made with crushed Fort St. Vrain (FSV) type TRISO fertile fuel particles. In addition, it describes the single cycle made with crushed FSV type TRISO fissile fuel particles on the 0.10-m secondary burner. Burner subsystem performance is discussed and the redesign of some

components is described. Results of a parametric study of burner process variables are presented and recommendations for future work are made.

Fig. 1-4. Overall view of 0.10-m secondary burner.

Fig. 1-5. Cross section of 0.20-m secondary burner.

Fig. 1-6. Installed burner system (Sheet 1 of 2).

Fig. 1-6. Installed burner system (Sheet 2 of 2).

2. DESCRIPTION OF EXPERIMENTS

The Activity Plan describing work to be done on the 0.20-m secondary burner included the following tests:

1. Two burner runs were performed for the purpose of burner shake-down and measurement of feed and product heat transfer coefficients. This was Phase I.
2. Seven burner runs were performed to generate data on four burner process variables by using a parametric manipulation of those variables. The first four runs, which constituted Phase II, were made on different days; the last three runs, made in quick succession over a 17-hour period, constitute Phase III.
3. One burner run was made to note the differences between combustion of crushed FSV type fissile fuel particles and combustion of the fertile particles used in all previous operations. This run, Phase IV of the testing, was made on the 0.10-m secondary burner due to a shortage of FSV, fissile fuel particles.

A series of acceptance criteria detailed the performance levels that would meet the test objectives. Burner inspections were also required at predetermined intervals, including leak tests, distortion, and crack propagation.

This section describes in detail all of the actual burner runs that were made to fulfill the Activity Plan.

2.1. PHASE I TESTS

2.1.1. 0.20-m Secondary Burner Heat Transfer Coefficients

Heat transfer coefficients were measured using both crushed feed and burned product from the 0.20-m secondary burner during Runs 1 and 2. The tests simulated the use of several burner wall temperature limitations since heatup and tail-burn of the secondary burner are limited by wall temperature. Fluidizing gas flow was varied only at the 900°C wall temperature.

The purpose of the tests was to determine the basic characteristics of the fluid bed in the range of normal operation. This provides input to future burner design efforts and improves knowledge of the present design.

2.1.1.1. Experimental Procedure. Feed heat transfer coefficients were measured using Run 2 feed, and product measurements were obtained using Run 1 product. The automatically controlled induction heater was actuated, causing the system to heat up to yield a steady-state temperature profile. When the temperature stopped changing, data on induction power input, heat losses, and temperature distributions were logged (see Table 2-1). The heater and/or gas flow setting was then varied to hield another data point.

2.1.1.2. Calculation Procedure. The overall heat transfer coefficient across the burner wall and fluid bed interface is determined as follows:

$$U = \frac{Q}{A \Delta \bar{T}} ,$$

where Q/A is the heat flux through the wall and $\Delta \bar{T}$ is the average difference between the outside wall temperature and the bed temperature.

The inside heat transfer coefficient h_i is calculated as follows:

$$U = \frac{1}{\frac{1}{h_i} + \frac{t}{K}}$$

TABLE 2-1
HEAT TRANSFER DATA AND RESULTS,
CRUSHED FSV FERTILE PARTICLE HEAT TRANSFER COEFFICIENT MEASUREMENTS

	CO ₂ Flow (SLPM)	Max. Wall Temp. (°C)	Induction Power (kW)	Coil Water Flow (LPM)	Coil ΔT (°F)	Capacitor Water Flow (LPM)	Capacitor ΔT (°F)	Average Wall-to- Bed ΔT (°C)	Heat Flow Area (cm ²)	Net Heat Flow (kW)	U $\left(\frac{\text{cal}}{\text{sec-cm}^2\text{-}^\circ\text{C}}\right)$	h_i $\left(\frac{\text{cal}}{\text{sec-cm}^2\text{-}^\circ\text{C}}\right)$	U $\left(\frac{\text{cm}}{\text{sec}}\right)$	Bed. Temp. (°C)	U $\left(\frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}\right)$	h_i $\left(\frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}}\right)$
<u>Feed</u>																
1	400	900	68	45	10	7.5	8	85	4780	48	0.0284	0.0394	70	760	210	291
2	360	900	65	45	10	7.5	8	82	4620	45	0.0285	0.0395	63	765	211	292
3	320	900	63	45	10	7.5	8	79	4620	42	0.0276	0.0379	57	770	204	280
4	280	900	59	45	10	7.5	8	76	4455	38	0.0270	0.0368	50	775	199	271
<u>Product</u>																
5	400	900	68	45	10	7.5	8	78	5115	47	0.0279	0.0385	71	775	206	284
6	440	900	75	45	10	7.5	8	85	5280	54	0.0288	0.0400	78	770	213	295
7	360	900	58	45	9	7.5	8	69	4950	38	0.0267	0.0362	65	790	197	267
8	360	850	53	45	8	7.5	6	63	5115	37	0.0276	0.0379	62	745	204	280
9	360	800	50	45	8	7.5	5	66	5115	34	0.0242	0.0326	59	700	179	241
10	360	750	45	45	8	7.5	5	71	5115	29	0.0192	0.0245	57	655	142	181

or

$$h_i = \frac{K}{\frac{K}{U} - T},$$

where t = wall thickness = 0.64 cm,

k = wall conductivity,

$k = 0.065$ cal/cm-sec- $^{\circ}\text{C}$ at 900°C ,

$= 0.060$ cal/cm-sec- $^{\circ}\text{C}$ at 800°C ,

$= 0.055$ cal/cm-sec- $^{\circ}\text{C}$ at 700°C .

The total heat input Q is defined as:

Q = induction power - coil water heatup - capacitor water heatup -
electrical line losses - heat conducted out of both ends of
susceptor - heat conducted out of both ends of burner wall.

Induction power is measured using a kilowatt meter at the motor generator. Water flows and temperatures are part of the recorded data. Axial heat conduction from the susceptor and wall is calculated using plots of temperatures, shown typically in Fig. 2-1. The total heat conduction was 0.5 kW. Electrical line losses were 0.3 kW.

Both the area of heat transfer A and the average temperature difference between the bed and wall ΔT must be taken from temperature profiles, shown typically in Fig. 2-1. The heat transfer area and points are defined as those points where the bed and wall temperatures cross. Heat is flowing into the bed in the region where the wall temperature is above the bed temperature. The average temperature difference is obtained by step-wise integrated averaging of the temperature difference. The number of data points and the interpolated temperature profiles have a significant effect on the calculated value for ΔT .

Fig. 2-1. Feed heatup No. 1 temperature profile

Calculation of U and h_i is then possible from knowledge of Q , A , ΔT , k , and t . Experimental data and results are given in Table 2-1 and are plotted in Figs. 2-2 and 2-3. A typical set of calculations is shown in Table 2-2.

In the range investigated, an increase in the heat transfer coefficient occurs as a result of higher velocity or higher bed temperature, with the latter having a much stronger effect. It should be noted that increases in velocity and bed temperature give rise to higher heat losses from the bed, so that the actual heating rate (and equilibrium temperature) may be lower with increased velocity (even though the heat transfer coefficient is higher).

A quantity of 125 kg of FSV TRISO fertile Type 5A fuel particles was screened to $-850 \mu/+425 \mu$, sampled for uncrushed and crushed properties, and split into two identical 60-kg batches, one for Run 1 and one for Run 2. This material was crushed in a roll crusher to make feed for the secondary burner. The physical properties and composition of the particles before and after crushing are given in Table 2-3. Their size distributions are shown in Fig. 2-4.

2.1.2. Run 1

2.1.2.1. Operation. Figures 2-5 through 2-7 show the parameters such as gas flow, composition, and temperature as a function of run time.

Initial actions included crushing the feed material into the feed hopper. The crusher was actuated at 22-rpm roll speed using 30% voltage on a variable speed 520-W (3/4-hp) dc motor and gear reducer. Whole particles were then choke fed to the crusher, which subsequently stalled. An increase in motor voltage to 50% coupled with manual starting of crushing action allowed crushing to proceed at 36-rpm roll speed. The motor is evidently not capable of crushing at 30% voltage. The crushing rate is shown in Fig. 2-8. A purge of 15-SLPM CO_2 gas was provided continuously to the vented feed hopper to avoid material oxidation prior to introduction of the burner.

Fig. 2-2. Effect of temperature on heat transfer coefficient

Fig. 2-3. Effect of velocity on heat transfer coefficient

TABLE 2-2
FEED HEAT TRANSFER COEFFICIENT
(see Fig. 2-1 for temperature profile)

Wall temp.	= 900°C max.
Bed temp.	= 760°C
Gas flow	= 400 SLPM CO ₂ (70 cm/sec)
Induction power	= 68 kW
Cooling water losses	= 20 kW
Net heat flow	= 48 kW (11,500 cal/sec)
Heat flow area	= 4780 cm ² (29-in. height)
Mean wall-bed ΔT	= 87°C
Max. wall-bed ΔT	= 140°C

$$U = \frac{Q}{A \Delta T} = \frac{11,500}{(4780)87} = 0.0277 \frac{\text{cal}}{\text{cm}^2\text{-sec-}^\circ\text{C}} \left(204 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}} \right)$$

$$h_i = \frac{k}{\frac{k}{u} - t} = \frac{0.065}{\frac{0.065}{0.0277} - 0.64} = 0.0381 \frac{\text{cal}}{\text{cm}^2\text{-sec-}^\circ\text{C}} \left(281 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}} \right)$$

or, using max. ΔT rather than mean ΔT
and using total susceptor area:

Total susceptor area = 5280 cm² (81-cm height)
Max. ΔT = 140°C

$$U = \frac{11,500}{5280(140)} = 0.0156 \frac{\text{cal}}{\text{cm}^2\text{-sec-}^\circ\text{C}} \left(115 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}} \right)$$

$$h_i = \frac{0.065}{\frac{0.005}{0.0156} - 0.64} = 0.0184 \frac{\text{cal}}{\text{cm}^2\text{-sec-}^\circ\text{C}} \left(136 \frac{\text{Btu}}{\text{hr-ft}^2\text{-}^\circ\text{F}} \right)$$

TABLE 2-3
FEED MATERIAL CHARACTERISTICS, PHASE I OF
THE 0.20-m SECONDARY BURNER TEST PLAN

Uncrushed Feed

Bulk $\rho = 2.17 \text{ g/cm}^3$

Tap $\rho = 2.31 \text{ g/cm}^3$

Crushed Feed

Bulk $\rho = 2.27 \text{ g/cm}^3$

Tap $\rho = 2.12 \text{ g/cm}^3$

Angle of response = 29°

$d_{SV} = 212 \text{ }\mu\text{m}$

57.1% $\text{ThC}_2 = 34,260 \text{ g}$

21.2% C = 12,660 g

21.8% SiC = 13,080 g

<0.1% unbroken particles,
determined by screen and
microscopic examination

Fig. 2-4. Crushed and uncrushed feed size distributions, 0.20-m secondary burner Phase I

Fig. 2-5. Off-gas composition versus time, 0.20-m secondary burner Run 1

Fig. 2-6. Gas flow and pressure drop versus time, 0.20-m secondary burner Run 1

Fig. 2-7. Temperatures versus time, 0.20-m secondary burner Run 1

Fig. 2-8. Particle crusher throughput, 0.20-m secondary burner Run 1

Feed material was added to the burner using the gravity pneumatic feeder at 40-SLPM CO_2 flow. The burner was being purged at 240-SLPM CO_2 during this time. Four minutes were required to add the entire batch of 60 kg of crushed fuel particles.

Heatup was then begun on automatic control at 70-kW maximum output limit. After 30 minutes of heating, the lowest bed thermocouple had not responded indicating a lack of axial bed mixing. When the inlet gas flow was readjusted to 400 SLPM, the lower bed temperature rapidly rose to 450°C . This caused the lower Gray-loc hubs to heat rapidly with an attendant increase in the clamp-to-hub temperature differential. In order to keep the differential below the design limit of 170°C , it was necessary to manually decrease the induction power to 50 kW for about 10 minutes followed by a return to the 70-kW limit.

After a total heatup time of 100 minutes, the bed reached 700°C . Filter blowback was actuated at 272 kPa (40 psi) with each of three banks receiving a 1-sec pulse every 30 seconds for an overall rate of one pulse per 10 seconds. This kept the filter pressure drop below 2.5 kPa (10 in. H_2O) throughout the run.

Ignition was effected by raising the inlet O_2 concentration from 0% to 20% and then stepping up to 100% in discrete steps over a 20-minute period. Induction power dropped off automatically as the bed heated above 860°C . Cooling air to the upper jacket was on automatic with a 650°C filter temperature setpoint. Lower cooling air was controlled manually during this run. Cooling air flows overran the chart span so rates are not available for this run.

Bed slugging was greater initially with maximum pressure variations of over 15 kPa (60 in. H_2O) at 6-second intervals, while late in the run they were a maximum of 7.5 kPa (30 in. H_2O) at 6-second intervals.

The full burn rate ended after 50 minutes when the concentration of CO in the off-gas decreased to zero. Inlet oxygen concentration was then

reduced to 60% to preclude the possibility of a pure oxygen front penetrating the bed and reacting with fine carbon on the filter surface. Ten minutes after this was done, oxygen did begin to exit from the burner, increasing to 20% over the next 20 minutes. In the following 20 minutes, the inlet oxygen concentration had to be decreased to 20% to keep the outlet below the run limit of 20%; at this time the burn rate had dropped to a negligible point (greater than 4 g/min carbon burn rate).

The induction heater had come back on automatically as the bed temperature dropped below 860°C and was able to hold the bed at 790°C during this low combustion rate period.

At the end of the run, the upper end of the burner was vibrated to dislodge any fine particulates adhering to the wall. Particulates are filtered out of the burner off-gas stream by sintered metal filters in the upper end of the burner. The filters are periodically blown back to return material to the fluidized bed. A significant amount of material, 200 g or 0.4% of the product, reentered the bed and was burned after the filter region was vibrated. A permanent method of vibrating the burner filter region would be of definite benefit in lowering product carbon content.

A series of product heat transfer tests were then carried out, followed by product removal at room temperature. Use of too low a transport velocity caused choking flow and subsequent plugging in vertical portions of the conveying line.

2.1.2.2. Analysis. Disassembly of the lower end of the burner revealed material both above and below the distributor plate. This probably resulted from the fact that the drilled hole size was too large and insufficient pressure drop existed across the plate. This problem has been investigated in depth and is reported in Section 3.1.

The product material properties are shown in Table 2-4. A thorium material balance closed within 4%, which is probably within the limits of

TABLE 2-4
PRODUCT MATERIAL CHARACTERISTICS FOR 0.20-m SECONDARY BURNER
RUNS 1 AND 2 WITH FSV FERTILE PARTICLE FEED

Run 1

74.9% ThO₂ = 33,742 g

1.7% C = 766 g

23.4% SiC = 10,542 g

Initial product = 42,810 g

Material above distributor plate = 720 g

Material in gas plenum = 1,520 g

45,050 g

Bulk ρ = 2.37 g/cm³

Tap ρ = 3.03 g/cm³

Angle of repose = 34.5°

$\frac{Th_{out}}{Th_{in}}$ = 0.96

Run 2

Initial product = 44,173 g (1.4% C)

Material above distributor plate = 930 g (7.7% C)

Material in gas plenum = 1,758 g (2.2% C)

46,861 g

Overall
1.6% C

Bulk ρ = 2.67 g/cm³

Tap ρ = 3.43 g/cm³

Angle of repose = 37°

Fig. 2-9. Product size distribution, 0.20-m secondary burner Runs 1 and 2

Fig. 2-10. Off-gas composition versus time, 0.20-m secondary burner Run 2

Fig. 2-11. Gas flow and pressure drop versus time, 0.20-m secondary burner Run 2

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Fig. 2-12. Temperature versus time, 0.20-m secondary burner Run 2

Fig. 2-13. Particle crusher throughput, 0.20-m secondary burner Run 2

the sampling error. The product contained just under 1 wt % unbroken fuel particles. The product size distribution is shown in Fig. 2-9.

Following this initial run, welds identified in the maintenance procedures, MM524701, were inspected using a liquid dye penetrant technique. No cracks were found in any location.

2.1.3. Run 2

2.1.3.1. Operation. Figures 2-10 through 2-12 contain data gathered during the burn run.

Feed material was crushed at 36 rpm roll speed with a throughput as shown in Fig. 2-13. Four minutes were required to add the 60-kg bed of crushed fuel particles. Induction heating proceeded while a 400-SLPM CO₂ gas stream fluidized the bed. A total of only 65 minutes was required to heat the fluid bed from ambient to 700°C. This reduction in time is attributed to the use of a higher fluidizing gas rate, which yielded better bed mixing. Clamp-to-hub temperature differentials were under the 170°C limit throughout the heatup period. The automatic induction heater control system continued to work very well.

The fluid bed was then used for a series of heat transfer coefficient measurements using CO₂ gas. During these measurements, an estimated 2.5 kg of carbon were displaced from the burner by a $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$ reaction. Initially, 15.9 kg of burnable carbon were in the feed.

Ignition was again at 700°C, with a stepped ramp of oxygen taking 20 minutes to reach 100% inlet oxygen. A flow totaling channel kept the total oxygen flow at 400 SLPM throughout the run. The operator adjusted only the desired oxygen flow; the totalizer then adjusted the CO₂ flow rate. Induction power and cooling air were both on automatic control. The lower cooling air controller was not tuned well enough resulting in an oscillation in bed temperature of $\pm 25^\circ\text{C}$ within a period of about 10 minutes. Further tuning should decrease this cycling.

Filter blowback was set at the same interval as in the first test. Using 340-kPa (50-psi) blowback, the maximum filter pressure drop was 3 kPa (12 in. H₂O). The burner alignment mechanism (Peaucellier cells) worked well without binding, allowing the burner to grow down in a vertical direction only.

Inlet oxygen was reduced to 60% when off-gas CO decreased to zero. Off-gas oxygen appeared 25 minutes later and was controlled to less than 20% by reduction of inlet oxygen. Bed temperature was kept at 780°C by the induction heater. Burning was terminated 2 hours after finishing the pure oxygen burn period. No material holdup was observed in the filter chamber.

The bed was cooled to 100°C, followed by pneumatic product transport. Insufficient transport gas was again responsible for choking flow in vertical sections leading to line plugging.

2.1.3.2. Analysis. As shown in Table 2-4, the burner had material both above and below the distributor plate after product removal. Product size distribution is shown in Figs. 2-9 and 2-14.

One weight percent unbroken particles was again found in the product. The roll gap was checked using a strip of solder dropped through the rotating crusher rolls. It indicated no change in gap since it had last been checked before Run 1. Disassembly of the crusher has revealed wear on the side plates adjacent to the crushing section of the rolls. This wear and roll surface dimensional variations are currently being investigated to determine the cause of the uncrushed particles in both burner run products.

2.1.4. Conclusions

Activity Plan AP524701 details 10 acceptance criteria for Phase I operation:

Fig. 2-14. Product size distribution, 0.20-m secondary burner Run 2

1. No feed or product line blockage--The product line was blocked in both runs due to insufficient blower capacity.
2. Feed time less than 15 minutes--It was 4 minutes.
3. Product removal time less than 30 minutes--See criterion 1.
4. Bed heatup to 700°C in 1 hour, able to idle at 800°C--It takes 1 hour 5 minutes to heat to 700°C; can idle at 780°C.
5. Cooling system of bed kept at 900° $\pm$ 25°C--Yes.
6. Control system functions properly--Yes.
7. Distributor plate functions properly--No; new design required. See Section 3.1.
8. Filter pressure drop less than 12.5 kPa (less than 50 in. H₂O)--Yes.
9. No appreciable vessel leaks or cracks--Checked out acceptably.
10. No shroud frame deformation--Acceptable.

Criteria 1, 3, and 7 were not met, but corrective action was initiated. Criterion 4 was determined to be acceptable and criteria 2, 5, 6, 8, 9, and 10 were met.

Several problem areas were found in Phase I: (1) distributor plate hole size, (2) the use of undersized product transport blowers, and (3) roll crusher side plate wear. These deficiencies were corrected and were retested during Phase II. The distributor plate redesign is discussed in Section 3.1.

Sufficient data were obtained concerning automatic control to allow run sequence automation to proceed. Off-gas filter performance has been good, with low pressure drop at the present blowback rate. Phase II tests included variations in this filter blowback rate in an attempt to minimize both filter pressure drop and blowback gas requirements.

2.2. PHASE II TESTS

2.2.1. Run 3 (Figs. 2-15 through 2-18)

In this run, all variables were set at a baseline determined from previous 0.10-m secondary burner tests. They represented the best estimate of proper variable selection, and were as follows:

1. 700°C bed ignition temperature
2. 900°C bed operating temperature
3. 0.90 m/s bed superficial velocity
4. Two full blowback cycles per minute

Feed material for Run 3 was 60,000 g of crushed TRISO fertile FSV type fuel particles. It was acceptable feed for the burner and contained 0.1% unbroken fuel particles. The crusher roll gap was 0.495 mm (0.0195 in.) during Run 3 feed preparation. Forty-five minutes were required for feed preparation with a 44-rpm roll speed.

Feed addition to the burner required 4 minutes using the gravity pneumatic feeder. Bed heatup was initiated after feeding was completed and required 80 minutes to reach 700°C ignition temperature. At that time, a manual O₂ ramp was begun by jumping to 0.080 std. m³/min O₂ and then increasing to pure O₂ over a 20-minute period. Total flow was maintained at 0.402 std. m³/min at all times to yield 0.90 m/s superficial velocity at 900°C.

Fig. 2-15. Feed and product size distribution, 0.20-m secondary burner Run 3

Fig. 2-16. Fluidized bed and off-gas filter temperatures versus time, 0.20-m secondary burner Run 3

Fig. 2-17. Off-gas composition versus time, 0.20-m secondary burner Run 3

Fig. 2-18. Inlet gas flows and pressure drops versus time, 0.20-m secondary burner Run 3

Cooling air flow was manually adjusted to keep the fluid bed at 900°C. Following an initial 25°C overshoot, the bed stayed within 10°C of setpoint throughout the main burning period. This is well within the $\pm 50^\circ\text{C}$ called out in the Design Criteria (DC52701). Filter chamber annular cooling air was on during the entire main burning period, with a peak filter temperature of 775°C and a filter pressure drop of 3.5 kPa maximum.

When the off-gas CO concentration declined to zero, the inlet gas composition was changed from 100% to 60% to preclude a pure O₂ front from contacting the hot filter surface. Thirty minutes later, O₂ did penetrate the bed, but the filter had cooled from 720°C to 600°C and no filter area hot spots were detected by the thermowall.

The fluid bed then cooled to 800°C due to a lack of carbon to burn. Induction heating was on automatic to keep the bed hot without overheating the wall (900°C setpoint on wall temperature). Off-gas O₂ content was kept at 20% by modulating inlet O₂ content. A filter vibrator was used to help dislodge carbon from the filter area so that it could descend to the bed for combustion. The vibrator was of definite use as demonstrated by increased oxygen utilization following vibrator actuation.

Total run time when O₂ was present in the off-gas was 90 minutes. This was followed by cooling the bed to ambient in preparation for product removal. Using a 7.08 act. m³/min blower, the product was pneumatically transported as it exited the burner product valve located just above the distributor plate. The distributor sweep tube was actuated after the bulk of the product had left the burner, and the transport gas was intermittently drawn back through the burner off-gas filters to effect a cleanout of dust from the burner.

Disassembly of the burner revealed a heel of material resting on the distributor plate. The burner was then reassembled and fitted with an air-driven vibrator adjacent to the gas distributor to help move material off the plate. After a cleanout using the vibrator, the burner was again disassembled and had only a light coating of dust on the distributor and

some material in the outer edges. Total product weight left on the plate was 50 g, which amounts to 0.1% of total product weight. The product weighed 47,836 g and had a 1.5 wt % carbon content.

2.2.2. Run 4 (Figs. 2-19 through 2-22)

The ignition temperature and the superficial velocity for this run were changed to 650°C and 0.80 m/s, respectively, as part of the parametric study.

Feed preparation required 45 minutes at a 44-rpm roll crusher speed to process 60,000 g of TRISO fertile FSV type fuel particles. Feed addition took 3.8 minutes to complete, and bed heatup required 55 minutes to reach 650°C. Gas flow was 0.475 std. m³/min of CO₂ until the bed reached 300°C, at which time the flow was reduced to 0.362 std. m³/min (which yields 0.80 m/s superficial velocity at 900°C).

An automatic inlet O₂ flow ramp was used with an 0.080 std. m³/min initial jump and a 15-minute ramp time to pure inlet O₂. CO₂ flow was automatically adjusted to keep the total at 0.362 std. m³/min.

Cooling air flow was on automatic with an initial 50°C overshoot followed by $\pm 15^\circ\text{C}$ control. Controller settings were manipulated to help determine optimal values. Maximum filter pressure drop was 2.3 kPa with a peak filter temperature of 720°C. After 65 minutes of combustion, the off-gas CO concentration declined to zero, with inlet O₂ concentration lowered at that time to 60%.

For 60 minutes, the bed was burning sufficiently to maintain temperature at 850° to 900°C. After that time, the carbon content of the bed was such that 810°C was the maximum temperature attainable with the induction heater limited by a 900°C burner wall constraint. Off-gas O₂ content was again limited to 20% by adjusting the inlet O₂ flow rate. Total flow was gradually reduced over a 100-minute span to 0.226 std. m³/min, yielding 0.46 m/s (1.5 ft/sec) at 810°C. This allowed fines a better

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Fig. 2-19. Feed and product size distributions versus time, 0.20-m secondary burner Run 4

Fig. 2-20. Fluidized bed and off-gas filter temperatures versus time, 0.20-m secondary burner Run 4

Fig. 2-21. Off-gas composition versus time, 0.20-m secondary burner Run 4

Fig. 2-22. Inlet gas flows and pressure drops versus time, 0.20-m secondary burner Run 4

opportunity to reenter the bed than at the higher normal operating velocity of 0.80 m/s.

Product transport was initiated after cooling the bed to 140°C. Initial transport was unsuccessful due to bursting of a rupture disc attached to the transport blower suction line. This disc was installed to preclude overpressure of the product bunker, but it had not been designed to withstand the vacuum associated with pneumatic transport. It was then capped off, the lines were cleared manually, and the balance of the product was transported pneumatically to the product bunker. A 300-g heel (0.6% of the total product) remained on the distributor after the run, even after the distributor plate vibrator was used. Product carbon content was 1.2 wt %, which is an improvement over the last run and can be attributed, in part, to the reduced-velocity operation during final tailburn. As some product was lost due to the transport line cleanout, a total product weight could not be determined.

2.2.3. Run 5 (Figs. 2-23 Through 2-26)

In this run, ignition temperature was further lowered to 600°C while the main burn period superficial velocity was raised to 1.0 m/s as part of the parametric study.

Feed was 60,000 g of crushed TRISO fertile FSV type fuel particles.

Bed heatup required 45 minutes to reach 600°C. An O₂ ramp was used for ignition, as in Run 2, but with a 0.452 std. m³/min O₂ flow at the end of the ramp period. Cooling air was completely on automatic, yielding a 15°C initial overshoot and ±10°C control thereafter. This is very satisfactory procedure that will be used again in the future.

Filter pressure drop peaked at 5 kPa with a high filter temperature of 800°C. The main burning period lasted for 60 minutes until the off-gas CO concentration declined to zero. Inlet flow was then altered to 60% O₂, lowering the filter temperature to 600°C by the time that O₂ appeared in

Fig. 2-23. Feed and product size distributions, 0.20-m secondary burner Run 5

Fig. 2-24. Fluidized bed and off-gas filter temperatures versus time, 0.20-m secondary burner Run 5

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Fig. 2-25. Off-gas composition versus time, 0.20-m secondary burner Run 5

Fig. 2-26. Inlet gas flows and pressure drops versus time, 0.20-m secondary burner Run 5

the off-gas 35 minutes later. Off-gas O_2 content was not allowed to increase above 20% during the final tailburning period. Superficial velocity was again reduced to 0.46 m/s (1.5 ft/sec) over the span of the 100-minute tailburning period.

Product removal proceeded after the bed was cooled to 100°C. Twenty seconds after the product valve was opened, the system pressure drop became great enough to open a safety relief valve. The product valve was then closed to allow the transport line a chance to clear itself. This was followed by reopening and cleanout procedures.

A heel again remained on the distributor plate after the run. The function of the sweep tube was questioned at that time, so pressure gauges were installed. This revealed that the 6-mm (1/4 in.) CO_2 supply line was undersized so that only 276-kPa (40 psi) CO_2 was delivered to the sweep tube rather than the intended 689 kPa (100 psi). A 13-mm (1/2 in.) supply line was then plumbed in and the burner was reassembled. Following another cleanout procedure using the high-pressure distributor plate sweep tube, a 40-g heel of dusty material was left in the burner. This is an 0.08% heel and is quite acceptable.

Burner product weighed 47,229 g and contained 0.9 wt % carbon, which is the lowest amount yet attained in this burner. Use of low-velocity final tailburning will be continued.

2.2.4. Run 6 (Figs. 2-27 Through 2-31)

In Run 6, the off-gas filter blowback rate was increased to 3 cycles per minute from the baseline of 2 cycles per minute. The ignition temperature was lowered to 550°C following success in Run 5 at 600°C.

Feed consisted of 60,000 g of crushed TRISO fertile FSV type fuel particles.

Fluid bed heatup time to 550°C was 35 minutes. An inlet oxygen ramp was used leading to a pure O₂ inlet stream during main burning. At this low ignition temperature a 2-minute spike of 5% off-gas O₂ was noted. The automatic bed temperature control overshoot the set point, reaching 920°C and cycling twice before damping out. Control is achieved using cooling air modulation. Manual startup transient cooling air control will be used in the future, with subsequent automatic control following initial stable operation.

The filter pressure drop reached a maximum of 4 kPa at 770°C. The main burning period lasted for 50 minutes followed by inlet flow changes to 60% O₂ after off-gas CO decreased to zero. The filter temperature was 630°C when O₂ began to appear in the off-gas. During the final tailburning, off-gas O₂ content went through a short peak of 30% before decreasing to 20%. Bed temperature was held at $\geq 800^{\circ}\text{C}$ and the total flow was lowered to 0.32 m/s to help carbon fines return to the bed for final combustion.

Pneumatic transport was accomplished by discharging product intermittently through the product removal valve so as not to overload the vacuum-pneumatic transport system. A 32-g heel was left on the distributor plate, which amounts to an acceptably low 0.07% of the total product. Product carbon content was an equally acceptable 0.75%. This is the lowest carbon content yet attained, giving strong impetus to using low-velocity tailburning.

Fig. 2-27. Feed size distribution, 0.20-m secondary burner Runs 6 through 9

Fig. 2-28. Fluidized bed and off-gas filter temperature, 0.20-m secondary burner Run 6

Fig. 2-29. Off-gas composition, 0.20-m secondary burner Run 6

Fig. 2-30. Inlet gas flows and pressure drops, 0.20-m secondary burner Run 6

Fig. 2-31. Product size distribution, 0.20-m secondary burner Run 6

2.3. PHASE III TESTS

2.3.1. Run 7 (Figs. 2-32 Through 2-35)

This was the first run of the three-run series. The off-gas filter blowback rate was lowered to 1 cycle per minute from the baseline of 2 cycles per minute. All other variables were at the baseline levels.

Feed material in each of these three final runs was 60,000 g of crushed FSV TRISO fertile fuel particles. Fifty minutes were required to induction heat the fluid bed to 700°C, followed by a 20 minute period of ramping inlet O₂ to 100%. The bed temperature was held manually at 900°C initially, followed by automatic temperature control for the balance of the run. The peak off-gas filter pressure drop was 3.5 kPa at 775°C.

During tailburning, the total flow was dropped to 0.46 m/s while keeping off-gas oxygen levels at 20%. Product transport was carried out after cooling the bed to 100°C. Intermittent opening of the product removal valve prevented overloading the vacuum pneumatic transport line. This product removal technique was used in all of these final three burner runs. An enlarged capacity transport system was designed and ordered based on the data gathered during these tests.

Product carbon content was 0.6 wt %.

2.3.2. Run 8 (Figs. 2-36 Through 2-39)

In this second run of the three-run series, the only variable changed was the bed temperature, which was dropped to 875°C during the main burning period.

Ignition was at 700°C, following a 55 minute fluid bed heatup period. The cooling air requirement was 25 m³/min during the initial 30 minutes of the run, as compared with a 20 m³/min air flow when using a 900°C bed temperature set point. Otherwise, the burner was very stable, as in previous runs.

Fig. 2-32. Fluidized bed and off-gas filter temperature, 0.20-m secondary burner Run 7

Fig. 2-33. Off-gas composition, 0.20-m secondary burner Run 7

Fig. 2-34. Inlet gas flows and pressure drops, 0.20-m secondary burner Run 7

Fig. 2-35. Product size distribution, 0.20-m secondary burner Run 7

Fig. 2-36. Fluidized bed and off-gas filter temperature, 0.20-m secondary burner Run 8

Fig. 2-37. Off-gas composition, 0.20-m secondary burner Run 8

Fig. 2-38. Inlet gas flows and pressure drops, 0.20-m secondary burner Run 8

Fig. 2-39. Product size distribution, 0.20-m secondary burner Run 8

The peak off-gas filter pressure drop was 3 kPa at 740°C. Inlet flow was dropped at 0.45 m/s by the end of final tailburning. Off-gas O₂ levels were controlled at 20% during tailburning. The product carbon content was 0.5 wt %.

2.3.3. Run 9 (Figs. 2-40 Through 2-43)

This final run was to test operations at a bed temperature of 850°C. The bed was ignited at 650°C following 40 minutes of heatup. The cooling air requirement was elevated to 33 m³/min during the first portion of main burning and rose from this level to over 38 m³/min. The off-gas filter pressure drop reached a high of 2.5 kPa at 660°C. The total gas flow was lowered to 0.49 m/s by the end of the tailburning period. The product carbon content was 0.5%.

Disassembly of the lower spool piece revealed a 300 g heel of very fine powdered ThO₂-SiC mixture. It was pierced by jetting holes and was obviously filter chamber material that had rained down after the run. This represents 0.17% of the feed for this run series, which is thought to be acceptable.

2.3.4. Acceptance Criteria

Activity Plan AP524701 details ten acceptance criteria for the parametric study as listed below. All of these criteria were fully met.

1. No feed or product line blockage
2. Feed time less than 15 minutes
3. Product removal time less than 30 minutes
4. Bed heatup in 1 hr.; ability to idle at 800°C
5. Cooling system keeps bed within 25°C of set point
6. Control systems function properly
7. Distributor plate functions properly
8. Filter pressure drop less than 7.5 kPa
9. No appreciable leaks or cracks
10. No shroud frame deformation

Fig. 2-40. Fluidized bed and off-gas filter temperature, 0.20-m secondary burner Run 9

Fig. 2-41. Off-gas composition, 0.20-m secondary burner Run 9

Fig. 2-42. Inlet gas flows and pressure drops, 0.20-m secondary burner Run 9

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Fig. 2.43. Product size distribution, 0.20-m secondary burner Run 9

2.4. PHASE IV TEST

2.4.1. Crushed FSV Fissile Particle Burning

At present there are 16.5 metric tons of fissile fuel particles in the Fort St. Vrain HTGR core. In anticipation of the eventual operation and refueling of the FSV reactor, there is the task of oxidizing crushed, irradiated FSV fissile particles as part of the fuel reprocessing flowsheet. Toward that end, the Activity Plans for both the 0.10-m and 0.20-m secondary burners call for at least one run for each burner using a batch of unirradiated, crushed FSV fissile particles. These particle batches were made for practice prior to FSV fuel production and contain depleted, rather than enriched, uranium.

The purpose of the 0.10-m burner run was to provide any troubleshooting required prior to using the larger 0.20-m burner. A smooth and trouble-free 0.10-m burner run was completed. The second portion of Activity Plan AP524601 was completed and all acceptance criteria were completely met.

2.4.2. Burner Operation

Feed material was prepared using the fissile particle roll crusher. The size distribution is shown in Fig. 2-44. The average surface area to volume ratio diameter d_{sv} was 93 μm . The bulk density was 1.5 Mg/m^3 and the tap density was 1.9 Mg/m^3 . The angle of repose measured 29 degrees. The material composition was 23% ThC_2 , 6% UC_2 , 42% SiC , and 29% C.

The crusher motor current draw was 6.3 A or 560 W with 30-rpm roll speed. The crushing rate was 45 kg/h. The crusher stalled momentarily on initial crushing, but restarted after manual assistance.

The batch of 12 kg was introduced to the burner through the gravity pneumatic feeder system over a 3 minute period. The batch was fluidized with $0.10 \text{ std m}^3/\text{min CO}_2$ and induction heated over a 70 minute period to an ignition temperature of 650°C . Figures 2-45, 2-46, and 2-47 show the bed

and off-gas filter temperatures, the O_2 and CO_2 gas flow rates and the fluid bed and off-gas filter pressure drops, and the off-gas concentrations, respectively.

Ignition was effected by raising the inlet O_2 flow to 60% while the total flow remained at $0.10 \text{ std m}^3/\text{min}$. No oxygen was detected in the off-gas. Earlier experiments with FSV fertile particles had precluded the use of over 70% inlet O_2 concentration in order to eliminate the possibility of small agglomerate formation in the distributor plate region.

Process heat generated by combustion and induction heating the burner wall to 900°C yielded a fluid bed temperature of 850° to 880°C . Complete combustion was realized at this temperature. An interesting phenomenon occurred: the off-gas never contained carbon monoxide. This is a dramatic change from the up to 30% CO observed during crushed FSV fertile particle combustion. Fluidization was also very different with a lack of significant slugging. Bed pressure drop fluctuations were never more than $\pm 0.75 \text{ kPa}$ throughout the run. In addition, off-gas filter fine loadings were very reasonable with peak filter pressure drops of 4 kPa . Cooling air was not required during the entire burner run.

After 115 minutes of burning, oxygen utilization efficiency dropped abruptly from 100% to 0% over a 10 minute span. The oxygen front had penetrated the bed only after consuming all available carbon. The burner was then switched to pure CO_2 operation and allowed to cool to less than 100°C prior to product removal. Pneumatic transport of the product as it exited through the side-mounted product removal valve was trouble free. Subsequent burner lower spool piece removal showed that 100% burner cleanout had been realized; there was not even any dust left on the distributor plate.

Product analysis gave a size distribution as shown in Fig. 2-44. The bulk density was 2000 kg/m^3 and the tap density was 2600 kg/m^3 . The angle of repose measured 44 degrees. The product burnable carbon content was 0.2%.

Fig. 2-44. Feed and product size distributions, 0.10-m secondary burner, FSV fissile particle Run 1

Fig. 2-45. Fluidized bed and off-gas temperatures, 0.10-m secondary burner, FSV fissile particle Run 1

Fig. 2-46. Inlet gas flows and pressure drops, 0.10-m secondary burner, FSV fissile particle Run 1

Fig. 2-47. Off-gas composition, 0.10-m secondary burner, FSV fissile particle Run 1

Because of the smooth, trouble-free nature of this operation, no further burning tests were made with FSV type crushed TRISO fissile particles.

3. SUBSYSTEM PERFORMANCE

3.1. 0.20-m SECONDARY BURNER DISTRIBUTOR PLATE REDESIGN

Several problems were encountered involving the distributor plate during Runs 1 and 2 of 0.20-m secondary burner Activity Plan 524701. These led to redesign of the plate based on analysis of the evidence gathered in these two burner runs and experience previously gained during 0.10-m secondary burner development work conducted from 1973 to 1975.

3.1.1. 0.20-m Secondary Burner Operating Experience

The original distributor plate design is shown in Fig. 3-1. It has 121 holes 1370 to 1500 μm (0.054 to 0.059 in.) in diameter on a combination triangular and radial hole layout. Figure 3-2 shows the calculated and observed room temperature pressure drop across the plate as a function of CO_2 gas flow.

Operation of this plate during heatup tests using 820- μm -diameter BISO-coated ThO_2 fuel particles was satisfactory. Only a very small weight of material (less than 20 g) was found in the inlet gas plenum (beneath the distributor plate). This is believed to have resulted from the large hole size relative to the size of the particles.

Fluidization characteristics were acceptable during these BISO particle heatups, with maximum axial bed temperature differences of $\pm 10^\circ\text{C}$. Product removal was successful using the product removal valve coupled with the pneumatic transport system. The distributor plate sweep tube was used for final cleanout. No material was found above the plate when the burner was dismantled for inspection.

3

3-2

Fig. 3-2. Pressure drop across original distributor plate

Phase I of the Activity Plan was completed using 60-kg batches of crushed TRISO fertile FSV type fuel particles having an initial size distribution as shown in Fig. 2-4.

Operation of the burner throughout Run 1 was smooth and trouble-free. This was followed by a series of product heat transfer tests using the product ash. Product removal was hampered by low transport gas flow rates, so discontinuous dumping was required. The material was required to remain in the burner without an upflow gas purge through the distributor plate owing to emptying of the CO₂ supply tank over a weekend.

Final product removal was then carried out, followed by lower burner disassembly for inspection. It was determined that the gas coming through the distributor plate holes had "jetted" through the shallow bed, thus ending any fluidization of the bed. This material amounted to 720 g. Inspection of the lower plenum revealed that 1520 g of material had drained in past the distributor plate.

Run 2 yielded similar results with jetting holes evident. A total of 930 g were left on the plate, while 1758 g drained into the plenum. (There was no time when flow did not go up through the plate in this run.)

3.1.2. Pertinent Experience on 0.10-m Secondary Burner

As reported in Refs. 3-1 and 3-2, a gas distributor having 21 holes 1.7 mm (0.067 in.) in diameter was tried during two runs on the 0.10-m secondary burner. Gas jetting was noted following product removal, but there was no pneumatic transporter at that time, only a vented can to allow gravity bed drainage out of the product removal valve.

Another distributor having 71 holes 0.64 mm (0.025 in.) in diameter (see Fig. 3-3) was then designed and tested. Reduced individual jet strength led to decreased heel weights when dumping into the vented can. Figure 3-4 shows the room temperature calculated and observed distributor plate pressure drop as a function of gas flow rate.

3-5

Fig. 3-3. 0.10-m secondary burner distributor plate

Fig. 3-4. Flow-pressure drop characteristics of 0.10-m secondary burner distributor plate

A pneumatic transport system was added later. This system, coupled with a distributor plate sweep tube (a series of gas jets aimed downward at the distributor plate), resulted in complete burner cleanout. A total of eight burner runs have been made since then, with burner cleanout resulting in each run. With the 0.64-mm (0.025-in.) hole diameter, the material that drained back through the plate never amounted to more than a few grams.

3.1.3. Analysis and Redesign of 0.20-m Secondary Burner Distributor Plate

Experiences with both burners indicate that gas jetting must be minimized. The BISO particle bed was not subject to jetting because of the size and weight of these spheres; they rolled down over the jetted hole and eliminated the jet. These particles are too heavy to be blown aside by the jet. Secondary burner feed and ash have a steep angle of repose (29 to 36 degrees), which allows them to be lanced by the gas jet and not flow back. A reduction in hole size is necessary for this finer material, with an attendant increase in the number of holes.

Backflow of material into the plenum is another problem that is most likely caused by two factors:

1. The hole size is too large (relative to particle size), so material has a chance to drop through the plate if the gas velocity is too low.
2. The pressure drop across the plate is insufficient to keep the slugging action of the bed from pushing fine material back through at some short time when the slug falls back hard and back pressures the bed. Typical observed maximum pressure variation during a slug is 15 kPa (60 in. H₂O). The distributor pressure drop should be of this order to ensure against pressure surges pushing material through the plate.

Both of these factors may be dealt with in a judicious distributor design.

Figure 3-5 shows the relationship between hole size, number of holes, and pressure drop at room temperature. Since pressure drop increases with temperature, room temperature is the worst case (lowest plate pressure drop).

The pressure drop required to equal maximum bed pressure fluctuation is 15 kPa (60 in. H_2O). Hole size should be minimized to reduce jetting and solids backflow, but since experience has shown that 0.64 mm (0.025 in.) is effective, this size is chosen. From Fig. 3-5, it can be seen that approximately 260 holes are required. A pure radial layout pattern will be used to simplify the machining operation.

A distributor was made and used with these hole layouts throughout the following seven burner runs. A picture of that plate is shown in Fig. 3-6. The product valve is shown open and used. No backflow of material occurred during any of those tests. The average heel weight per run was 100 g. This is 0.17 wt % of the material used in each run. The heel does not increase as a function of successive runs, so a very small carryover heel will be part of the secondary burner operating cycle.

3.2. GRAVITY PNEUMATIC FEEDER SYSTEM

Loading the burner batchwise requires a feeder of high throughput to perform the job quickly while having a reasonably constant solids flow rate. The feeder must be as simple as possible while minimizing the possibility of blockages, and it must be capable of virtually complete cleanout for accountability purposes.

A gravity pneumatic feeder system, intensively studied on the 0.10-m secondary burner, was used in 49 separate burner runs. It was optimized during that time and recommendations were made in the 0.10-m secondary burner Interim Development Report (Ref. 3-2) for a feeder suitable for the 0.20-m secondary burner. The installed feeder is shown in Fig. 3-7. The feed preparation system is shown in Fig. 3-8.

Fig. 3-5. Distributor pressure drop variations

Fig. 3-6. Modified distributor plate (Sheet 1 of 2)
(product valve open)

Fig. 3-6. Modified distributor plate (Sheet 2 of 2)
(product valve closed)

Fig. 3-7. Installed gravity pneumatic feeder system

Fig. 3-8. Feed preparation system (Sheet 1 of 2)
(crusher feed bunker)

Fig. 3-8. Feed preparation system (Sheet 2 of 2)
(particle crusher)

During the nine burner runs on the larger burner, a total of 540 kg of crushed fuel particles were fed into the burner through the gravity pneumatic feeder system. Each batch of 60 kg took less than 4 minutes to add to the burner vessel, including feed hopper cleanout time. No heel remained in the hopper or feeder after batch addition operations.

These excellent results serve to verify the earlier development work. The feeder system will be used in the future without modification.

3.3. PRODUCT REMOVAL VALVE

In order to remove the product bed from each batch, a product removal valve is incorporated in the burner design. It consists basically of a circular valve that seats flush with the burner wall just above the inlet gas distributor. Product flows out through the valve into a pneumatic solids conveyor, which transports it to the next step in the flowsheet, the dissolver. This design was pioneered on the 0.10-m secondary burner, and the work is fully documented in the Interim Development Report (Ref. 3-2). Pictures are shown in Fig. 3-9.

Product valve usage on the 0.20-m secondary burner has been smooth and trouble free. After the nine burner runs, the valve still seats correctly and operates as designed. Discussion of distributor plate heel problems caused by jetting may be found in Section 3.1 and in Section 2.

3.4. INDUCTION HEATING SYSTEM

An induction heating system for use on fluidized-bed burners was developed by trying several induction coil configurations on the 0.10-m secondary burner. An annular susceptor was settled on as the best choice when supplied with jacketed cooling air; the susceptor and burner tube form the annulus for cooling air flow. The induction coil was placed outside of the susceptor with 2 inches of fibrous insulation in between the two. This work is explained in detail in Ref. 3-2.

Fig. 3-9. Product removal valve (Sheet 1 of 2)

Fig. 3-9. Product removal valve (Sheet 2 of 2)

On the 0.20-m secondary burner, a similar setup was constructed with the addition of a continuous external stainless steel sheath outside of the induction coil. This sheath was found to heat due to coupling with the induction coil. Analysis of the problem led to the conclusion that either a material with very high conductivity such as copper or aluminum or a material with very low conductivity such as fibrous insulation could be used to sheath the induction coil. Materials with an intermediate conductivity such as stainless steel heat up too much to be used. At present, a moldable fibrous insulation with a skin hardener is installed around the induction coil. This arrangement works quite well; it protects the coil and prevents electrical losses or stray induction fields from heating surrounding equipment.

Heatup rate of the lower Graylok flange proved to be a limiting factor in overall burner heatup time. The inner hub heats up as the fluid bed is heated and transfers heat to the surrounding clamp. A limit of 170°C clamp temperature lag forces the maximum total induction heater input to be no more than 70 kW. As described in the parametric study, this is enough power to heat the burner to ignition temperature in only 45 minutes. During tailburning, the fluid bed may be held at 800°C by using the induction heater. This allows burning of residual carbon from the already low carbon content bed. The induction heating system is shown in Fig. 3-10.

3.5. COOLING AIR SYSTEM

Use of cooling air is required during the main burning portion of the run to cool both the upper and lower sections of the burner vessel. Upper cooling air comes on first to keep the off-gas filters as cool as possible. Actual fluid bed cooling (through the lower annular jacket) is controlled on a feedback basis from bed temperature. This serves to keep the fluid bed at a very stable temperature during the main burning period. As bed carbon content declines and the heat generation rate falls off, lower cooling air decreases to zero followed later by upper cooling air flow when the off-gas filter temperature falls below 650°C.

Fig. 3-10. Induction heating system (Sheet 1 of 2)
(motor generator)

Fig. 3-10. Induction heating system (Sheet 2 of 2)
(cooling water recirculator)

No problems have been encountered with the cooling air system. The system is shown in Fig. 3-11.

3.6. OFF-GAS FILTRATION SYSTEM

In-vessel filters are incorporated to separate the off-gas flow from the particulate fines elutriated from the fluid bed. They are made of sintered Hastelloy X porous metal for use at the elevated temperatures encountered in the burner. The filters are identical to those used on the 0.10-m secondary burner during earlier development work described in Ref. 3-2.

A description of filter blowback optimization is found in Section 4. This is a very reliable and trouble-free system that performs the required job efficiently.

3.7. INSTRUMENTATION

Automated control of the 0.20-m secondary burner is accomplished using a digital process controller with an all analog input/output interface. This system is discussed in depth in Ref. 3-3. Basic actuation of burner supply valves, blowers, heaters, etc., is manually initiated using lighted pushbuttons. The complete operating procedure for the burner system is contained in the appendix. System operability has been excellent throughout all experimental tests. A minimum of supervisory control by the operator is required; during most of the burner run he is occupied with watching trends of key variables as printed on strip chart recorders. The burner instrumentation panels are shown in Fig. 3-12.

Fig. 3-11. Cooling air system
(blower)

Fig. 3-12. Burner instrumentation panels (Sheet 1 of 2)

Fig. 3-12. Burner instrumentation panels (Sheet 2 of 2)

REFERENCES

- 3-1 Rickman, W.S., General Atomic Company, "Evaluation of High Temperature Bed Removal System Integrated with a Pneumatic Transport System for Use on Secondary Burners," unpublished data.
- 3-2 Rickman, W.S., "Interim Development Report for Secondary Burning," ERDA Report GA-A13540, General Atomic Company, December 25, 1975.
- 3-3 Rode, J.S., "Process Control of an HTGR Fuel Reprocessing Cold Pilot Plant," General Atomic Report GA-A14101, October 1976.

4. SUMMARY AND RECOMMENDATIONS BASED ON A PARAMETRIC STUDY OF PROCESS VARIABLES

Analysis of the parametric study led to recommending the following values for process variables:

1. Fluid bed superficial velocity should be reduced from 0.90 to 0.80 m/s during the main burn period.
2. Ignition temperature should be lowered from 700° to 600°C.
3. Fluid bed temperature should be dropped from 900° to 850°C during the main burn period.
4. Filter blowback frequency should be reduced from 2 cycles/min to 1 cycle/min,
5. Fluid bed superficial velocity should be lowered to 0.45 m/s by the end of the tailburning period.

Burner process variables were manipulated to yield insight to burner operation and to help optimize burner cycle efficiency.

4.1. SUPERFICIAL VELOCITY STUDY

The effect of superficial velocity variation was studied in Runs 3 through 5. The superficial velocity was set at 0.90 m/s (the nominal value), 0.80 m/s, and 1.00 m/s for Runs 3, 4, and 5, respectively. Table 4-1 shows the effect of these varying flow rates on the cooling air requirement, filter temperature, and batch time reduction as a percent change from the nominal case. It can be seen that the 0.80 m/s flow rate uses less cooling air (19% less than the 1.00 m/s case), has less than

half the off-gas filter pressure drop, and has an 80°C lower off-gas filter temperature. These are important benefits considering that only a 4% increase in total batch time from the 1.00 m/s case is necessary. It is therefore recommended that the inlet gas flow in future operations be 0.80 m/s.

4.2. IGNITION TEMPERATURE STUDY

The ignition temperature was investigated in Runs 3, 4, 5, and 6 by igniting at 700°, 650°, 600°, and 550°C, respectively. Table 4-2 shows the effect on off-gas oxygen detected during startup and on the time to induction heat to the given temperature. Decreasing the ignition temperature reduced the heatup time except from 650° to 600°C, where a lower superficial velocity in the former test led to equalization of the heatup times. It is desirable to reduce the heatup time while not venturing into the region where initial O₂ ramped in bypasses the bed. This gives rise to the possibility of a CO-O₂ explosion since CO is always present during startup.

It is therefore recommended that the ignition temperature in the future should be 600°C to both minimize heatup time and to preclude formation of an explosive off-gas mixture.

4.3. FILTER BLOWBACK FREQUENCY STUDY

Increasing and decreasing the off-gas filter blowback frequency was done in three burner runs to minimize the filter pressure drop and temperature. As shown in Table 4-3, the surprising result is that no difference in peak filter pressure drop or temperature was noted. Work on the 0.10-m secondary burner had predicted a 20% decrease in pressure drop at the higher blowback rate and a corresponding increase at the lower rate. This simply did not prove to be true. The lower blowback frequency of 1 cycle per minute is therefore recommended.

TABLE 4-1
EFFECTS OF VARYING BURNER SUPERFICIAL VELOCITY

Run No.	Superficial Velocity (m/s)	Peak Cooling Rate (m ³ /min)	Maximum Filter ΔP (kPa)	Maximum Filter Temperature (°C)
3	0.90	32.0	3.5	775
4	0.80	29.5	2.3	720
5	1.00	36.2	5	800

TABLE 4-2
EFFECTS OF VARYING BURNER IGNITION TEMPERATURE

Run No.	Ignition Temperature (°C)	Heatup Time (min)	Startup O ₂ Spike
3	700	80	No
4	650	45	No
5	600	45	No
6	550	35	Yes - 5% for 3 min

TABLE 4-3
EFFECT OF VARIATIONS IN OFF-GAS FILTER BLOWBACK FREQUENCY

Run No.	Frequency (cycles/min)	Peak Filter Pressure Drop (kPa)	Peak Filter Temperature (°C)
3	2	3.5	775
6	3	3.5	775
7	1	3.5	775

4.4. BED TEMPERATURE STUDY

The effect of lowering bed temperature from 900°C to 875° and 850°C was studied in three burner runs. The major effects, as shown in Table 4-4, were a high cooling air requirement and a lower peak filter temperature at reduced bed temperatures. Coupling this with safer operation at lower temperatures favors the 850°C bed temperature.

The recommendation is to run the bed at 850°C while realizing that an approximately 20% higher cooling air flow will be required during 1 hour of the 5-hour cycle.

4.5. SUPERFICIAL VELOCITY DURING TAILBURNING

Superficial velocity during tailburning was not included in the original Activity Plan, but was investigated as a means to lower the final bed carbon content. Figure 4-1 shows the relationship between the superficial velocity during tailburning and the product carbon content.

A definite trend indicates that lower velocity at the end of the run allows more carbon fines to enter the fluid bed where they can be consumed.

The present Design Criteria DC524701 requires less than 2.0 wt % burnable carbon content in the burner product. Input from dissolution test results will finally dictate the maximum carbon content. Until that time, the burner will be operated to ensure that the product will contain no more than 1.0 wt % burnable carbon. This requires a superficial velocity during tailburning of no more than 0.45 m/s.

TABLE 4-4
EFFECTS OF VARYING BED TEMPERATURE

Run No.	Bed Temperature (°C)	Peak Cooling Air Required (m ³ /min)	Peak Filter Temperature (°C)
3	900	32	775
8	875	34	740
9	850	>38	660

Fig. 4-1. Effect of tailburning superficial velocity on product carbon content

ACKNOWLEDGMENTS

Much of the success of this experimental program is due to the help of others. As in most development work, it is the insight of the technicians actually working on the equipment that allowed the burner to become a smoothly functioning operation. Zac Zacavich, Bob Earle, and R. W. Wheatley were invaluable in this capacity; their ability to merge process considerations with mechanical reality was instrumental in keeping the burner operating reliably throughout the year. Tom Wright added his years of burner experience in guiding the technician support on this program.

Burner design and equipment fabrication was carried out by Dr. U Sun Park. His work was always of the highest quality and served to continue the spirit of excellence that has come to be associated with the secondary burner development program.

Technical support from several engineers was also very helpful through the year; this includes Paul Richards, Niles Johanson, Jack Baer, Harry Yip, and Bob Crabtree. Leadership for the pilot plant came from Bob Zimmerman and Jack Allen; they provided the overall objectives and the support required to meet them.

APPENDIX

OPERATING PROCEDURE

FOR PROTOTYPE FLUIDIZED-BED

CRUSHED PARTICLE BURNER

GENERAL ATOMIC COMPANY

GA 777 (Rev 5/74)

Operating Procedure: 20-cm (Prototype) Fluidized-Bed Crushed Particle Burner

Doc. No. OP 524701

Issue B

Date 6/1/77

ISSUE SUMMARY

APPROVAL LEVEL

2

Issue	Date	Prepared by	Approvals		Acceptance	Purpose of Issue/ Sections Changed
			Engineering	DRB	Project	
A RDD RELEASED 6/16/76	5/2/76	<i>U. S. Park</i> U. S. Park	<i>[Signature]</i>			Initial Issue, Release Basis, DI 524701, Issue D
DD RELEASED B 6/7/77	6/1/77	<i>W.S. Rickman</i> W.S. Rickman	<i>[Signature]</i>			General Revision per ECO 00450

Do not write in space below. Continue Issue Summary on GA Form 778.

GENERAL ATOMIC COMPANY

GA 541 (Rev 5/74)

Operating Procedure: 20-cm (Prototype) Fluidized-Bed Crushed Particle Burner

Doc. No. OP 524701

Issue B

Date 6/1/77

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I. SCOPE

This procedure describes the operation of the 20-cm prototype fluidized-bed crushed fuel particle (secondary) burner system. The secondary burner system described herein encompasses all the equipment and services between the inlet of the secondary burner feed bunker and the secondary burner product bunker, as depicted on the Piping and Instrumentation Diagrams, PI 524701 and PI 520101. This equipment includes the secondary burner; the burner feed and product bunkers and transport mechanisms; off-gas filtering, cooling and sampling systems; burner external heating and cooling systems; and the instrumentation and controls necessary to monitor system variables and to maintain them within operating ranges.

II. REFERENCES

- PF 524701 Process Flow Diagram 0 20-cm Fluidized-Bed Crushed Particle Burner
- PF 520101 Solids Handling
- PI 524701 Piping & Instrumentation Diagram - 20-cm Fluidized-Bed Crushed Particle Burner
- PI 520101 Piping & Instrumentation Diagram - Solids Handling
- Loop Drawing, Secondary Loop
- QAPD 3225 Quality Assurance Program Document
- DP 143-11 Experimental Data Recording, Identification and Retrieval

III. NORMAL OPERATIONA. Pre-Operational Procedures

Each run, either on a manual or an automatic control mode, should be preceded by the following procedures at least two days prior to operation. Since non-compliance with any of these procedures may either interrupt the process or nullify the test purposes, it is as IMPORTANT to follow them as to follow the main run procedures.

- a) Interface check
- b) Material supply check
- c) Feed preparation and sampling
- d) Burner off-gas analyzer calibration
- e) Instrument check

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- f) Control system check
- g) M-G set activation for induction heater

Control panel arrangement is attached after section b.

a) Interface Check

1. Check the roll crusher and Orbitran weigh cell operability with cognizant engineer.
2. Check the outlet valve 'CLOSED' for secondary burner feed bunker on control panel #5 (see following page).
3. Activate the roll crusher and vary the speed controller from 0 to 100. Observe the RPM change on roll crusher RPM gauge right above the control panel #5. Normal operation range is 30~60 RPM. Reduce the speed control to 0 and turn off the roll crusher.
4. Ensure that the secondary burner product bunker is 'EMPTY.' This may be checked using the bunker weight readout on control panel #6, with the Orbitran mode switch in 'N' position.
5. 'OPEN' the filter valve on control panel #5. Check the secondary product bunker outlet valve on panel #6 in 'CLOSE' position.
6. Select product transport button to 'MANUAL' mode and press the start auto product transport button 'ON.' Observe the vacuum gauge on panel #6 to reach 4-6 inches Hg. Turn off the auto product transport button.
7. Operate the cooling air system to check for excessive shroud air leakage.

b) Material Supply Check

1. Check the secondary burner feed bunker. This may be checked using the bunker weight readout on panel #5, with the Orbitran mode switch in 'N' position. At least 60 kg of particles are needed for a batch.
2. Check CO₂ supply tank outside E-building. Make sure that the supply is enough for the run (100 kg for 1 cycle, 300 kg for an 18-hour run, and 400 kg for a 4-cycle continuous run campaign). The CO₂ tank capacity (full) is 600 kg. If the charge is below 30% full, report to cognizant engineer for refill.
3. Check O₂ supply tank outside E-building. Ensure that there is adequate supply for a run (120 kg for single cycle and 18-hour runs and 480 kg for a 4-cycle continuous run campaign). If the charge is below 30% full (full capacity is 5874 kg), report to cognizant engineer for refill.

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ABOVE THE PANEL

ATTACHMENT # _____

% AMP
TO GCO

TIMER
(SEC.)

RPM
ROLL CRUSHER

TIMER
(MIN.)

DATE	TIME	TEST NO.	TESTER	REMARKS
10/10/77	14:00	101	J. H. HARRIS	1st Run - OK
10/10/77	14:15	102	J. H. HARRIS	2nd Run - OK
10/10/77	14:30	103	J. H. HARRIS	3rd Run - OK
10/10/77	14:45	104	J. H. HARRIS	4th Run - OK
10/10/77	15:00	105	J. H. HARRIS	5th Run - OK
10/10/77	15:15	106	J. H. HARRIS	6th Run - OK
10/10/77	15:30	107	J. H. HARRIS	7th Run - OK
10/10/77	15:45	108	J. H. HARRIS	8th Run - OK
10/10/77	16:00	109	J. H. HARRIS	9th Run - OK
10/10/77	16:15	110	J. H. HARRIS	10th Run - OK

FRONT PANEL CABINET NO. 6 PROTOTYPE COUNTRY ROOM		10/10/77 16:00
GENERAL PURPOSE 10/10/77		10/10/77 16:00

ATTACHMENT # _____

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4. Check the water supplies to induction M-G set, burner off-gas heat exchanger and to the cooling air heat exchanger (turn them 'ON').

c) Feed Preparation and Sampling (Control Panel #5)

1. Check the switches on the control panel (#5) between (and including) the feed hopper outlet valve and the roll crusher and ascertain that they function properly.
2. Turn the switch on feed bunker weighing system to 'N' position. Check the weight indicator to see if there is an adequate supply of fuel particles (60 kg) in the bunker.
3. Turn the above switch from 'N' to 'R' position.
4. Press the 'TARE' button. The weight indicator should show zero weight after TBD seconds.
5. Press the 'FEED HOPPER VENT' button 'ON.'
6. Press the 'FEED HOPPER PURGE' button 'ON.'
7. Check the feeder 'OUTLET VALVE' in 'CLOSE' position.
8. Turn (or check) the roll crusher speed control to zero position.
9. Press the 'ROLL CRUSHER' button 'ON.'
10. Turn the roll crusher speed control knob until the roll crusher RPM gauge above the panel reaches 2000 RPM, if necessary.
11. Press the feed bunker 'OUTLET VALVE' to 'OPEN.' Check and readjust the roll crusher speed to 2000 RPM, if necessary.
12. When the weight indicator shows 60.0 kg, 'CLOSE' the feed bunker 'OUTLET VALVE.' (It takes approximately 45 min. to crush 60 kg of fuel particles.)
13. Reduce the roll crusher speed control to zero.
14. Press the 'ROLL CRUSHER' button to 'OFF.'

The following steps 15 through 18 are to be followed only when feed material samples are taken for analysis.

- * 15. Take approximately 500 g of crushed particles into a sampling bottle through the sampling port. Weigh and record the net weight.
- ** 16. Split the sample into two parts. Screen one part of the material through the following screens: 500, 425, 355, 300, 250, 212, 180, 150, 125, 106, 90, 75, 63, 53, 45 and 37 μ (U.S.

* Material data sheet is attached.

** Steps 16 through 18 may be performed after burner run is completed.

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Run Number _____

☐ Feed Material

☐ Product Material

Secondary Burner Material Analysis

Screen Analysis

Screen Size	Wt, g.	Δ %	Cum. %
+ 500			
- 500			
- 425			
- 355			
- 300			
- 250			
- 212			
- 180			
- 150			
- 125			
- 106			
- 90			
- 75			
- 63			
- 53			
- 45			
TOTAL			

bulk density = $\frac{\text{g}}{\text{cc}}$ = _____

tap density = $\frac{\text{g}}{\text{cc}}$ = _____

angle of repose =
ARCTAN $\left[\frac{\text{height}}{1/2 \text{ base}} \right]$ = _____

Carbon Analysis

	in	out
wt. sample + tare		
wt. tare		
wt. sample		

Analysis by _____ Date _____

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- ** 17. Split out approx. 100 g of crushed particles, weigh it in a burn tray, put it in a muffle furnace overnight at 800°C (with the furnace door cracked open) and reweigh it. Record the weight difference. Split the ash down to two 1-2 g samples to be sent for Th analysis in cardboard pill boxes. A typical request for analysis form is shown on the following page.
- ** 18. Determine the bulk density in a 100 ml graduated cylinder by gently pouring the crushed material in. Check tap density by impacting the cylinder on a solid object for ~30 seconds to settle the solids. Record the weights of material and volumes on the material data sheet.

d) Burner Off-Gas Analyzer Calibration

The gas analyzer pumps a continuous sample of burner off-gas through O₂, CO and CO₂ analyzers at set pressure and flow rates. Calibration requires running known gases through the analyzers to set zero and span.

- Purge burner with CO₂
- Open valves 9, 10, 1, 2
- Close valves 4, 5, 12
- Move selector valve 11 on 2°
- Move selector valve 3 on 'sample'
- Turn on sample pump
- Adjust valve 6 to give 0.3 CFH on rotometer 1
- Adjust valve 7 to give 3.0 CFH on rotometer 2
- Note pressure P on gauge - it will be used again
- Set CO₂ span to 100%, O₂ zero to 0%, CO zero to 0%
- Move selector valve 11 to 'air'
- Adjust valves 6, 7 and 13 to yield P pressure and specified rotometer settings
- Set O₂ span to 21% and CO₂ zero to 0%

Repeat until no further analyzer adjustments are necessary.

- Close valves 9, 10
- Open valve 4
- Turn valve 3 to calibrate
- Adjust valves 7, 8 to yield P pressure and specified rotometer readings on #2 rotometer only
- Set CO span to 29%

** Steps 16 through 18 may be performed after the burner run is completed.

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REQUEST FOR CHEMICAL ANALYSIS

LABORATORY REPORT

GA-FORM-146 REV. 1/74

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- Open valves 10, 9
- Close valve 4
- Move selector valve 11 to "20 cm 2°," valve 3 to "sample"
- Adjust valves 6 and 7 to yield P pressure and 0.3 CFH on rotometer 1 and 3.0 CFH on rotometer 2

e) Instrument Check

All instruments are regularly checked and calibrated according to the Maintenance Manual and Department Procedure 143-3. Before each run, however, the following instruments should be checked for their operability:

- Thermocouples (continuity)
- Differential pressure (DP) cells
- Alarms
- Recorders (enough paper and proper inking)

(Any malfunction should be reported to the instrument technician as well as to the cognizant engineer.) In addition, perform the following steps:

1. Set (or check) the filter blowback cam timer at one minute and the interval at one second.
2. Set the valve guide purge regulator at 15 psi.
3. Set the valve actuator regulator at 60 psi.
4. Adjust the DP cell purge rotometers to 10 CFH.
5. Adjust the feeder gas flow to 40 CFH and the purge to 6 CFH.
6. Adjust the feeder clean-out gas flow to 70 CFH and the purge to 6 CFH.
7. Adjust the feed hopper purge gas to 40 CFH.
8. Check I/P supply regulators. Set @ 25 psi.

f) Control System Check

The 20-cm prototype secondary burner shares the central Diogenes Process Control System* with both 20-cm and 40-cm primary burners. Proper switch-over to 20-cm secondary burner and system check, therefore, are required before each run.

* Use of the Diogenes Process Computer is described in a separate operator's manual. The control loops and scaling data are shown in the referenced loop drawings and scaling data tables.

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1. Transfer the thermocouple connectors behind the control panel #3 (inside lower left side) to 20-cm prototype secondary burner.
2. Switch three relays next to the thermocouple connectors to:
 - PROTO (PROTO/RESEARCH)
 - PROTO (PROTO, 20-cm 1°/10-cm 2°)
 - All 2° (All 1°/All 2°)
3. Actuate each switch on the 20-cm secondary burner control panel (panel #5) BELOW (and not including) the feed hopper outlet valve and ascertain that it is functioning.
4. Check the CFM (Channel Function Matrix) board to ensure that all the pins including the "PARITY" are properly entered to match the control loops.
5. Punch in each channel to ensure that scaling data are properly entered.
6. Place all loops in central manual control mode.
7. Operate gas flow ramp with off-gas analyzer operating; check calibration.
8. Check filter and distributor DP as function of gas flow rate.

g) M-G Set Activation for Induction Heater

1. Lock out access to the burner pit.
2. Actuate recirculating water pump and open water supply valves to yield the following water supply pressures:

M-G Set	17 psig
Auto transformer	60 psig
Coils	45 psig
Capacitors	45 psig

3. Select 20-cm secondary burner on 3-position switch.
4. Close 600A circuit breaker.
5. Push MG protect reset switch.
6. Start motor with key switch.
7. Switch field on - wait for time delay to close relay.
8. Push start button - this allows the system to be operated from the control room.

B. Operational Procedures

The 20-cm secondary burner is operated from the central process control room.

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1. Feeding

- a. Put control loops in Diogenes in "AUTO" mode. Leave P025, F242, P056 & P262 in manual @ 0 output.
- b. Start the recorder charts and the time mark.
- c. Activate both the O₂ and the CO₂ supplies by pressing the buttons on the panel. Observe that both buttons light.
- d. "CLOSE" the feed hopper vent line and CO₂ purge.
- e. "OPEN" the feed hopper outlet valve.
- f. Activate the feeder actuator.
- g. Observe the bed DP reading on the recorder. It should increase during the feeding (it takes approximately 4~5 minutes to complete the initial feeding).
- h. When DP reading levels off, activate feed hopper vibrator and the clean-out port gas for a minute.
- i. Turn "OFF" the feed actuator, vibrator and clean-out flow.
- j. "CLOSE" the feed hopper outlet valve.
- k. Actuate filter blowback as needed to keep filter DP below 10" H₂O.

2. Start-Up

- a. Turn the "HEAT" switch "ON" to close the induction heater contactor switch. Switch P025 to automatic.

The following steps will progress automatically. Observe the temperature changes to identify any system malfunction.

- b. The burner wall temperature will be limited to 900°C.
- c. When the bed temperature reaches 600°C, CO₂ flow decreases and oxygen ramp starts to bring the oxygen flow to 357 SLPM and "NO" CO₂ flow.
- d. When the bed temperature reaches 820°C, the induction heater output gradually decreases until it reaches zero level.
- e. When the filter temperature reaches 350°C, upper cooling air valve comes on; turn on cooling air blower, then set P262 on automatic.
- f. When the bed temperature reaches 850°C, lower cooling air flow is increased to maintain the bed temperature at 850°C; after ten minutes, it may be switched to automatic on F242.

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3. Steady State

The following operations are done automatically. Operator should always observe the temperatures to identify any upset condition or system malfunction.

- a. O₂ flow is maintained at a constant level, 357 SLPM.
- b. Bed temperature is controlled by the lower cooling air and maintained at 850°C.
- c. Filter chamber temperature is controlled by the upper cooling air.

4. Tail-Burn and Soaking

When the off-gas CO level drops below 2%, the following steps will progress automatically. Operator should pay attention to the filter chamber temperature and the off-gas oxygen concentration to identify possible upset conditions and system malfunction.

- a. Inlet O₂ concentration is dropped to 60% while keeping the same total inlet flow.
- b. Lower cooling air flow continues until bed temperature drops below 850°C.
- c. Upper cooling air flow continues until the filter chamber temperature drops below 650°C.
- d. When the off-gas O₂ concentration reaches 20%, O₂ flow decreases to maintain 20% O₂ in the off-gas. CO₂ flow makes the difference in flow rate.
- e. When the bed temperature falls to 820°C, the induction heater starts and increases to maintain the bed temperature at 850°C.
- f. When the induction heater no longer maintains the bed at 850°C, the bed temperature drops further until it reaches an equilibrium level. Actuate the filter vibrator at 5 minute intervals to dislodge fines from the metal surfaces.
- g. Lower inlet flow to 200 SLPM in 20 LPM steps over a 30 minute period after the off-gas O₂ reaches 20%
- h. Soak the bed material at this equilibrium temperature.

5. Shut Down

- a. Turn off induction heater.
- b. Cool the bed with forced air convection
- c. When the bed has cooled to 300°C, shut off the cooling air.

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- d. Check if the filter valve is at "OPEN" position.
- e. Check and "CLOSE" the product bunker outlet valve.
- f. Turn the feed bunker weigh system mode switch to "R."
- g. Press the "TARE" button and observe the weight indicator reads zero weight.
- h. Activate the "PTO" system to "Manual" mode.
- i. "START" the product transport.
- j. Select the "PART OPEN" mode.
- k. "OPEN" the product valve. The vacuum gauge on panel #6 should increase and the weight indicator should go up (note: the weight increase will be indicated with a negative number).
- l. After TBD minutes, "FULL OPEN" the product valve and at the same time "CLOSE" the filter valve.
- m. Observe the weight indicator (numerical) on panel #6. When the weight increase slows down, activate the distributor plate sweep for 10 seconds for every 30 seconds until the weight indicator no longer changes. Use the distributor plate and filter chamber vibrators throughout.
- n. "STOP" the product transport and "CLOSE" the product valve.
- o. Record the final product weight.
- p. Turn "OFF" the filter blowback.
- q. Turn "OFF" all purge line gases.
- r. Turn "OFF" M-G set.
- s. "OPEN" the 600A circuit breaker.
- t. Turn "OFF" all cooling waters when the equipment is cooled.
- u. Turn "OFF" the sample pump.

C. Product Analysis

1. Split out 1.5 kg of product from the product and record the weight.
2. Split the product to ~250 g for screen analysis. Screen through the following screens: 425, 355, 300, 250, 212, 180, 150, 125, 106, 90, 75, 63, 53, 45 and 38 μ (U.S. standard sieve series 40, 45, 50, 60, 70, 80, 100, 120, 140, 170, 200, 230, 270, 325, and 400 mesh). Record the cut weights. Use the same material data sheet used for feed material.
3. Split out ~200 g for carbon analysis. Weigh the sample on a furnace tray and heat it to 800°C in a muffle furnace (crack open the door to admit air) overnight. Split out 4 samples (~1.5 g each)

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of the ash and send two of them to Analytical Chemistry Lab. in a cardboard pill box for Th analysis. (Use the same request form as for the feed analysis). Keep the other two samples until the results from the Analytical Chemistry Lab. are received.

4. Use a 100 ml graduated cylinder to determine bulk and tap densities of the product. Get tap density by impacting the cylinder repeatedly for ~30 seconds to settle the material.
5. Determine the angle of repose by pouring material through a funnel onto a flat surface until a pile about 1-2" high is formed.

IV. PROCESS UPSETS AND TRANSIENTS

All important process parameters are monitored by the thermocouples, DP cells and gauges on control panels. Whenever any process parameter fluctuates beyond normal operating range due to process upsets, corrective action is required to bring the parameter back to normal range. The following alarms are provided to alert the operator (via a flashing light and beeper) and to initiate necessary actions:

<u>Condition</u>	<u>Alarm Set Point</u>
1. High bed temperature	950°C
2. High burner vessel temperature	905°C
3. High susceptor temperature	1100°C
4. Low CO ₂ supply pressure	100 psi
5. Low O ₂ supply pressure	100 psi
6. High multipoint temperature	1100°C
7. High blower discharge temperature	82°C

Each individual upset and transient condition and its corrective action is described below.

A. High Bed Temperature (alarm #1 above)

Reduce O₂ flow until the bed temperature drops to 850°C. When the upset condition disappears, the bed temperature will remain at 850°C with a reduced amount of cooling air flow. Increase the O₂ flow back to normal operating range.

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B. High Local Bed Temperature

High local bed temperatures can be identified from a multipoint recorder reading. For a local high temperature, the cooling air flow will not automatically increase to reduce the temperature. Reduce O₂ flow and increase the cooling flow. When the process stabilizes, increase the O₂ flow back to normal operating range. Cooling air will be automatically compensated with the control in auto mode.

C. High Burner Vessel Temperature with Induction Heater "ON" (alarm #2 above)

Reduce the M-G field voltage to lower the susceptor heat radiation. For a faster response, bring in the cooling air flow in addition. When the upset condition disappears, switch both the induction heater (M-G field voltage control) and the cooling air back to automatic control mode.

D. High Burner Vessel Temperature with Induction Heater "OFF" (alarm #2 above)

Reduce O₂ flow and increase the cooling air flow. When the process stabilizes, increase the O₂ flow to normal range and switch the cooling air flow to automatic mode.

E. High Susceptor Temperature (alarm #3 above)

Reduce the M-G field voltage to lower the temperature to a safe level. The response is very fast. Continue the process with the induction heater in a manual control mode.

F. High Filter Chamber Temperature

Reduce O₂ flow and increase the upper cooling air flow. If O₂ appears in the off-gas, further reduce O₂ flow until no O₂ is in the off-gas. CO₂ flow will automatically maintain a proper fluidization of bed material. When stabilized, increase O₂ flow without exceeding TBD% O₂ in off-gas.

G. High Blower Discharge Temperature (alarm 7 above)

High blower discharge temperature reduces the maximum burner cooling capacity. Reduce O₂ flow and manually increase CO₂ flow to keep a constant flow of 357 SLPM. When blower discharge temperature exceeds 93°C, it shuts off completely and the burner loses the cooling air. In this case, take an emergency action as described in Section R-2.

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H. High Multipoint Temperature (alarm 6 above)

The case will fall to one of the above upset conditions. Take a proper corrective action described in paragraphs A through G.

I. Low Bed Temperature

Increase the O₂ flow (without exceeding 350 SLPM) and reduce the cooling air flow. If the temperature falls below 850°C, the induction heater will be turned on automatically.

J. Low Induction Heater Power Output

If the power output is substantially lower than the power demand, operate the induction heater manually. Increase M-G field voltage to obtain desired power without exceeding the temperature limits on the bed, vessel and the susceptor.

K. Low O₂ Supply Pressure (alarm 5 above)

No immediate action is required. Run the burner with reduced O₂ flow level. For a total loss of O₂ flow, refer to the emergency procedures.

L. Low CO₂ Supply Pressure (alarm 4 above)

Operate the burner at a reduced burn rate. If CO₂ flow rate cannot maintain proper fluidization, refer to the emergency procedures (Section R-7).

M. Loss of M-G Power

Reduce the induction heater control to zero power level and continue the process. Restart the M-G set following the procedures described earlier. Restart should be preceded by proper identification and correction of the causes for the loss of M-G power.

N. High Off-Gas O₂ Level

If O₂ level in off-gas exceeds 30%, reduce O₂ flow to bring the O level in off-gas below 30%. CO₂ flow will automatically compensate the low O₂ flow in order to maintain proper fluidization.

O. High Filter DP

A high DP itself does not pose any immediate danger unless it is accompanied with a high filter temperature. In any case, reduce the oxygen supply so that no oxygen appears in the off-gas and employ maximum cooling for the upper section. If a high filter DP persists, reduce the total flow to 275 SLPM and check for the malfunction of filter blow-back system.

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P. High Burner Pressure

This will invariably accompany a high filter DP. Use the same corrective action as stated above.

Q. High CO in Off-Gas

Avoid any coexistence of CO and O₂ in the off-gas by reducing the oxygen flow. However, this condition has never been encountered in the 10-cm secondary burner.

R. Emergencies1. Loss of Diogenes Computer

All process interface loops on Diogenes automatically go on "back up" mode with valves and controls held where last set by the computer. Operation is then fully manual from the PIMs (Process Interface Modules).

2. Loss of Cooling Air Blower

This will be seen by the cooling air flow recorder falling off to zero and by a sharp increase in bed temperature. Immediate shutdown should be taken. (Shut off O₂ flow immediately by a manual PIM control. CO₂ flow will be automatically increased to 275 SLPM to keep the materials fluidized.)

3. Loss of All Electrical Power

CO₂ flow goes fully open (F.O. valve) while O₂ flow is shut off (F.C. valve). Cooling air is lost as is vent suction. Wait until the power restores. Do not manually cut off the CO₂ supply even after the burner is cooled. It is important to keep the materials "floated" in the burner.

4. Temperature Excursion

An uncontrollable temperature excursion necessitates an emergency shutdown. Shut off O₂ flow (CO₂ flow will automatically maintain the bed materials fluidized). Shut off the induction heater, if used, and open the cooling air valves to their maximum capacity.

5. Feeder Malfunction

No bed differential pressure increase during feeding is an indication of feeder malfunction.

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6. Loss of O₂ Flow

Complete loss of O₂ flow does not pose an immediate danger. CO₂ flow will maintain a proper fluidization of bed materials. Cool the burner with maximum air cooling capacity. If O₂ flow cannot be re-stored, transfer the bed material into the product bunker.

7. Loss of CO₂ Flow

Control manually. Use maximum upper cooling air flow. Operate the burner at 800°C with 275 SLPM O₂ flow using the lower cooling air as a control mechanism. When the process approaches to tail end, quench the burner with maximum air cooling.

8. Simultaneous Loss of O₂ and CO₂ Flow

Shut off the induction heater, if used, and cool the burner with maximum air flow.

S. Faults1. Burner Wall Failure

A sudden bed pressure drop will occur as bed materials exit the burner. Shut down O₂ and cooling air flow immediately. Manually adjust the CO₂ flow to 100 SLPM to cool the bed material.

2. Filter Failure

This will be indicated by a sharp drop in filter differential pressure (this situation is likely to follow a sudden uncontrollable increase in filter chamber temperature). Shut off O₂ flow immediately. Shut down the induction heater, if used, and increase the cooling air flow to its full capacity. Manually readjust the CO₂ flow to 100 SLPM. When the bed temperature drops to 500°C, withdraw the bed materials to the product bunker.

V. SAFETY REQUIREMENTS

General Pilot Plant safety rules apply to 20-cm secondary burner. The following precautions should be strictly followed since they pose immediate hazards to operating personnel if not followed.

A. Radioactive Material Handling

The "Radiological Safety Course" is a prerequisite for all operating personnel to work on the burners. The GAC Radiological Safety Manual and the health physicists are sources of help in specific operations. In general, gloves, shoecovers, and red-collar lab coats are required. All radioactive material transfers should be made either in a vented hood or in closed containers via airlocks.

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B. High Frequency - High Voltage Electrical Equipment

All cables are installed in code-approved conduits. The bus-bars and the capacitors in the pit are exposed. Because of this, access to the pit should be restricted while the motor-generator is actuated. This will be done with a key lockout of the stairway, flashing red warning lights, and warning signs.

C. Hot Burner Exterior Surface

The hot burner exterior surface will exist during runs and for at least several hours thereafter. If access to the pit is desired during this time, asbestor gloves must be used for equipment contact. Warning signs will be displayed.

VI. Q.A. REQUIREMENTS

- A. All quality assurance activities shall be done according to the Quality Assurance Program Document, QAPD-3225.
- B. Experimental data recording, identification and retrieval shall follow the Department Procedure, DP 143-11.

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