A HIGH TEMPERATURE TEST FACILITY FOR STUDYING ASH PARTICLE CHARACTERISTICS OF CANDLE FILTER DURING SURFACE REGENERATION

B.S.-J. Kang, E.K. Johnson and J. Rincon
Mechanical and Aerospace Engineering Department
West Virginia University

Keywords: Hot Gas Filtration, Candle Filter, Filter Surface Regeneration.

Introduction

Hot gas particulate filtration is a basic component in advanced power generation systems such as Integrated Gasification Combined Cycle (IGCC) and Pressurized Fluidized Bed Combustion (PFBC). These systems require effective particulate removal to protect the downstream gas turbine and also to meet environmental emission requirements. The ceramic barrier filter is one of the options for hot gas filtration. Hot gases flow through ceramic candle filters leaving ash deposited on the outer surface of the filter. A process known as surface regeneration removes the deposited ash periodically by using a high pressure back pulse cleaning jet. After this cleaning process has been done there may be some residual ash on the filter surface. This residual ash may grow and this may lead to mechanical failure of the filter.

A High Temperature Test Facility (HTTF) was built to investigate the ash characteristics during surface regeneration at high temperatures. The system is capable of conducting surface regeneration tests of a single candle filter at temperatures up to 1500^{o}F. Details of the HTTF apparatus as well as some preliminary test results are presented in this paper. In order to obtain sequential digital images of ash particle distribution during the surface regeneration process, a high resolution, high speed image acquisition system was integrated into the HTTF system. The regeneration pressure and the transient pressure difference between the inside of the candle filter and the chamber during regeneration were measured using a high speed PC data acquisition system. The control variables for the high temperature regeneration tests were (1) face velocity, (2) pressure of the back pulse, and (3) cyclic ash built-up time.

The High Temperature Test Facility

The HTTF system consists of a chamber, an air preheater, a gas control unit, a water cooling system for pressure sensors, a temperature control unit, a data acquisition system and an image capturing system, as schematically shown in Figure 1.

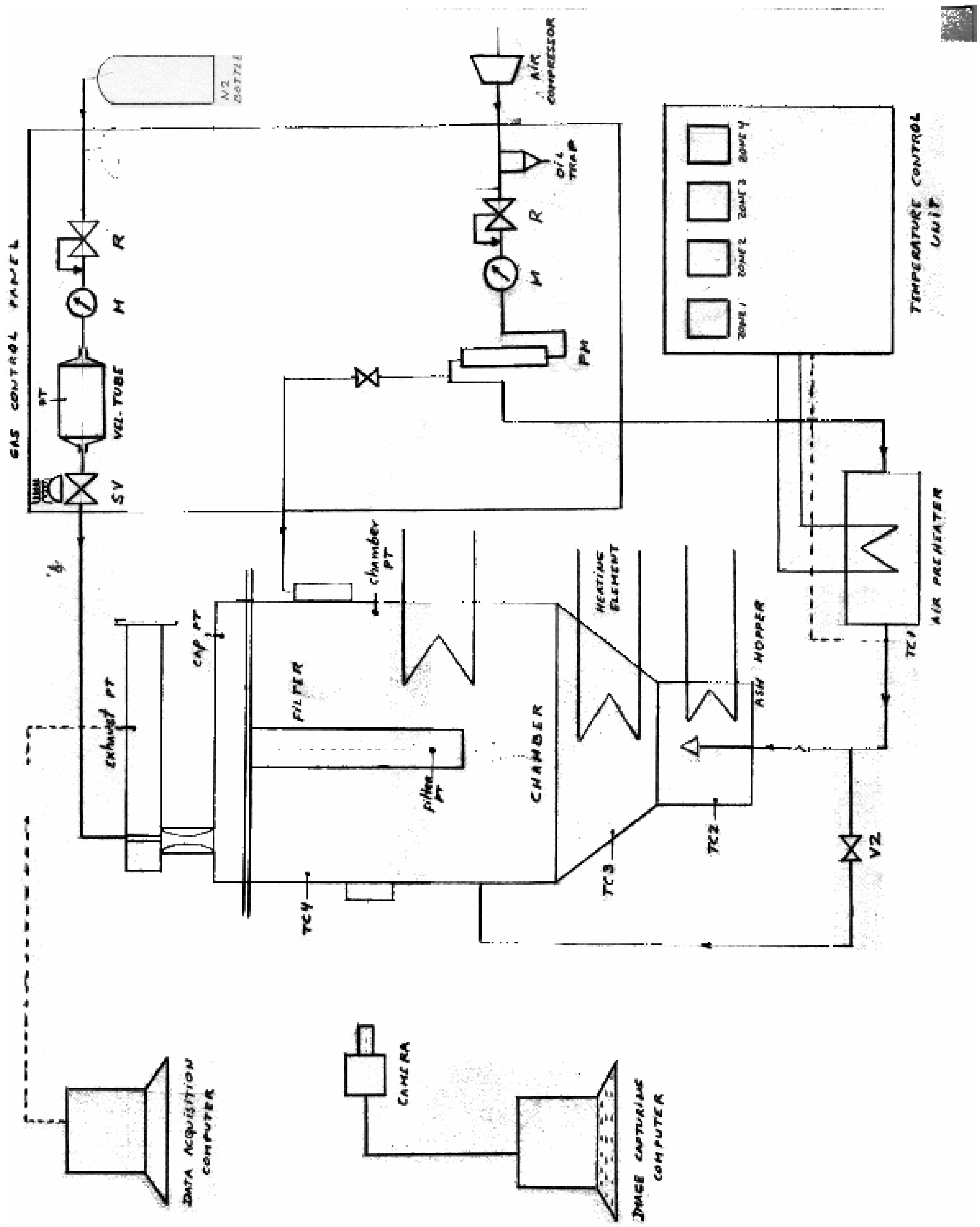


Figure 1 The High Temperature Testing Facility

The HTTF chamber is essentially an electrically heated oven which is constructed of stainless steel with heating elements mounted on the outside wall of the steel frame and then covered by a 1.5 inches thick thermal insulation layer of alumina silica. A single filtration element (candle filter) was mounted inside the chamber where the hot gas filtration process took place.

For a typical hot ash particle upstream operation, a continuous stream of hot air flows through a nozzle in the ash hopper at the bottom of the HTTF. The hot air flow disperses the particles in the ash hopper. The fluidized stream of particles then flow through the chamber and to the candle filter. The gases then flow through the filter and the ash particles are trapped on the filter surface.

The chamber has been built with a quartz window in each wall. The image capturing system takes pictures through one of them while a light source system projects a parallel light through another window. The windows are positioned in sets of two at two different elevations for image acquisition of surface regeneration at two locations of the candle filter. The selection of quartz windows is necessary for its high temperature resistance as well as its low thermal expansion coefficient in order to avoid breakdowns in the cooling down period after each test.

All the windows have internal metallic shields which can be opened or closed depending on whether regeneration pictures are to be taken. Continuous gas (air) injection is provided between the shield and the quartz window in order to keep the internal surface clean, which is crucial for obtaining good quality images.

The air preheater is a Pebble Bedded Heat Exchanger (PBHE), which can raise the gas (air) to the desired temperature. The PBHE consists of a forty-inch long stainless steel pipe (diameter: 4.25 inch, thickness: 0.135 inch) which is filled with 1/4" diameter alumina-silica balls (for the purpose of increasing total surface area for heat transfer as well as mixing the air for a more uniform temperature distribution). The unit is thermally insulated with a three inch thick layer of a soft-hard combination of alumina-silica.

The gas (air) from the preheater enters the chamber at two points (see Figure 1). The V1 valve controls the air going to the ash hopper, while the V2 valve controls air going to the side port, thus bypassing the ash hopper. In this way the system can simulate the actual regeneration process in an IGCC or PFBC power plant, i.e., keeping the flow of gas (air) through the filter when a regeneration is taking place. Specifically, when V1 is opened with V2 closed, the ash is being fluidized and filtration occurs at a specified face velocity. When V2 is opened with V1 closed, the fluidization of ash is stopped, the concentration of particles near the ash layer is significantly reduced while the face velocity is maintained.

The gas control panel has two separate gas lines, one for air and the other for nitrogen. The air line supplies air at the desired flow and pressure to the air preheater. An oil trap was installed to ensure an oil free air for the experiments, thereby avoiding potential problems at high temperatures.

The nitrogen line has a pressure regulator to set up a suitable reservoir pressure for the back pulse. A velocity tube was installed with a pressure sensor attached to it. This configuration gives pulse pressure information during the regeneration period. A normally closed solenoid valve was installed in the nitrogen line, to be triggered by the data acquisition system for the start of the surface regeneration process.

A temperature control unit was used to keep the air inside the chamber at the desired temperature condition during the test runs. The temperature was controlled through four independent heating zones with a total power rating of 28.8 Kw. The first zone is the air preheater with a power rating of 10.8 Kw. Zone two is the ash hopper section at the bottom of the chamber with a 3.6 Kw heating element attached. Zone three is the middle part of the chamber with a heating element of 7.2 kw. Zone four is the upper portion of the chamber with a 7.2 Kw heating element. Each zone has its own thermocouple connected to the temperature controller.

The HTTF system has pressure sensors placed inside the chamber, filter, cap of the chamber, and exhaust tube of the chamber. Each pressure sensor has proper water cooling protection to prevent overheating damage. Also, an uncooled pressure sensor is placed in the velocity tube for measuring the back pulse pressure. The data acquisition system is used to record all the pressure information from the pressure sensors.

The image capturing system is capable of recording sequential high resolution pictures (1024 x 512 pixels) of the regeneration process at 60 frames per second for 20 seconds. The imaging acquisition is triggered by a signal coming from the solenoid valve in the nitrogen line. A long distance microscope is attached to the CCD camera and is capable of measuring resolution down to 25 micron at a distance of one meter to the object.

Experimental Procedure

The procedure consists of three main steps. In the first step the filter inside the chamber as well as the internal walls of the chamber and the windows must be properly cleaned of any ash before starting a new test. Initially V1 should be closed and V2 should be opened. This will avoid any ash fluidization during the heating up process.

In the second step the chamber is brought up to operating temperature. The desired air target temperature for the test must be set in zone 4 of the temperature control unit. Temperature readings should be recorded at least every half hour during the process, which usually takes between 3 and 4 hours.

In the third step, when the air inside the chamber has reach stable temperature conditions, the filtration process may now commence. The data acquisition system is now activated, and V1 must be opened and V2 must be closed.

After the filtration period has been completed, V1 must be closed and V2 opened in order to let the free particles settle while maintaining a face velocity on the ash layer. Then two windows are opened for the image-capturing event of filter surface regeneration. The onset of image capturing of surface regeneration is triggered by the signal coming from the solenoid valve. This step is repeated as many times as cycles are required for the specific temperature condition.

System Performance and Preliminary Results

Many "dry" tests were conducted on the HTTF system from room temperature up to 1500 ^{o}F to ensure the integrity and performance of the HTTF. Preliminary cyclic ash layer build-up and surface regeneration tests using the HTTF system were conducted at 1100 ^{o}F, 1200 ^{o}F, and 1300 ^{o}F. Additional tests are being conducted for temperatures up to 1500 ^{o}F. The test conditions selected correspond to those of room temperature tests which will also be reported at this conference [2]. Coal ash sample obtained from the Power System Development Facility (PSDF) at Wilsonville, AL was used at both room and elevated temperatures regeneration tests.

The basic test conditions were (1) Face velocity: 5 cm/s, (2) Regeneration pressure: 95 psi, and (3) Build-up time: 20 minutes. Pressure history data for the pressure drop across the filter (filter pressure – chamber pressure) was obtained at the three test temperatures. The results are shown in Figures 2, 3, and 8. Figure 4 shows a thick ash regeneration at 1100 ^{o}F for the first cycle. A thin ash regeneration at 1100 ^{o}F for the second cycle is shown in Figure 5. Figure 6 shows a thin ash regeneration at 1200 ^{o}F for the first regeneration cycle. Figure 7 shows a thick ash regeneration at 1200 ^{o}F at the fourth regeneration cycle. Comparing the high temperature test results up to 1200 ^{o}F with the room temperature results [2], the ash surface regeneration characteristics are about the same, except that it is easier for residual ash formation at elevated temperatures. However, when testing at 1300 ^{o}F, we have observed quite a different ash surface regeneration behavior. Figures 9 to 11 shows ash regeneration at 1300 ^{o}F at cycles 4,5, and 6. We noted that no ash regeneration was observed for cycles 1 to 4, as typically shown in Figure 9. The ash layer thickness just simply built up and at cycle 5 a partially successful ash regeneration was observed, as shown in Figure 10. There is evidence of residual ash layer after cycle 5, as shown in Figure 10 (t = 0.83 seconds image). After cycle 5, no ash regeneration was observed, as typically shown in Figure 11. It is important to point out the pressure profiles shown in Figure 8 for the 1300 ^{o}F test case, which has the opposite trend when comparing to Figures 2 and 3. We believe this is due to the chemical/physical property changes of coal ash, i.e. the coal ash is getting stickier at temperature above 1300 ^{o}F, as such the ash surface regeneration characteristics differ substantially with those of lower temperature tests. It is possible that residual ash can be built up on candle filter while maintaining filter surface porosity. Monitoring the chamber pressure alone may not be sufficient to provide early indication of filter surface residual ash build-up. We plan to conduct a series of ash surface regeneration tests up to 1500 ^{o}F to further study this research issue.

Conclusions

An HTTF system has been designed and constructed. Temperature and pressure sensors and instrumentation associated with the HTTF system were also developed and calibrated. Preliminary filter surface regeneration tests were conducted at temperatures

1100 ^{o}F, 1200 ^{o}F, and 1300 ^{o}F Test results indicate that pressure history profiles are consistent with those obtained at room temperature for tests up to 1200 ^{o}F and a much faster residual ash formation was observed in the elevated temperature tests. However, preliminary test results at 1300 ^{o}F showed drastic different ash regeneration characteristics, which may be due to the increase of ash stickiness above 1300 ^{o}F.

Acknowledgement

This work is supported by US DOE grant no. DE-FC26-99FT40203. The authors wish to acknowledge the encouragement and support of Richard Dennis, Ted McMahon, and Jenny Tennant at NETL, and Richard Bajura at NRCCE, WVU, during the course of this investigation.

References

1. Gregory, Sean, "Development of Candle Filter Measurement Techniques," MSME Thesis, Mechanical & Aerospace Engineering Department, West Virginia University, 2001.
2. Vasudevan, Venkatesh, "Study on Candle Filter Surface Regeneration Characteristics at Room Temperature," MSME Thesis, Mechanical & Aerospace Engineering Department, West Virginia University, 2002.

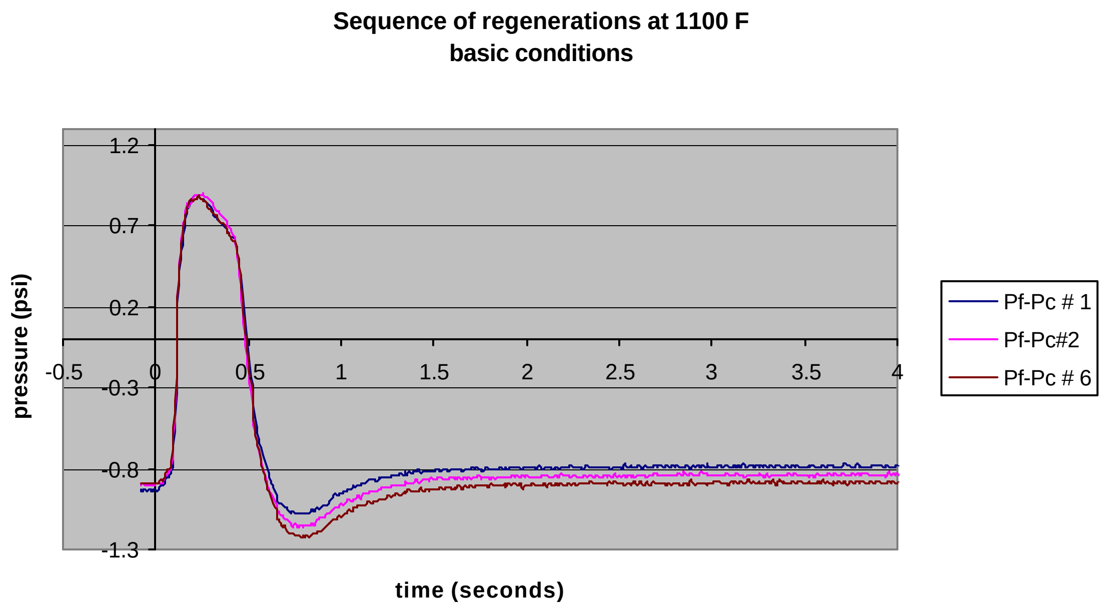


Figure 2 Pressure profiles during surface regeneration at 1100 ^{o}F.

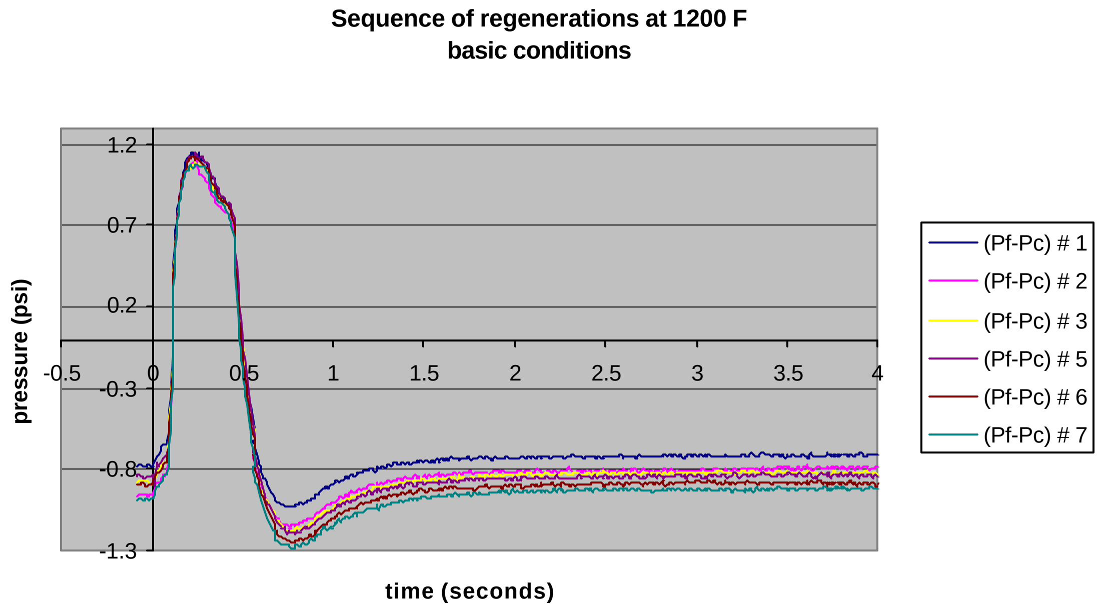
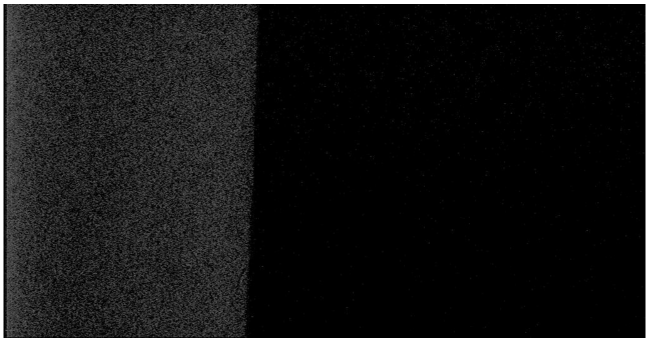
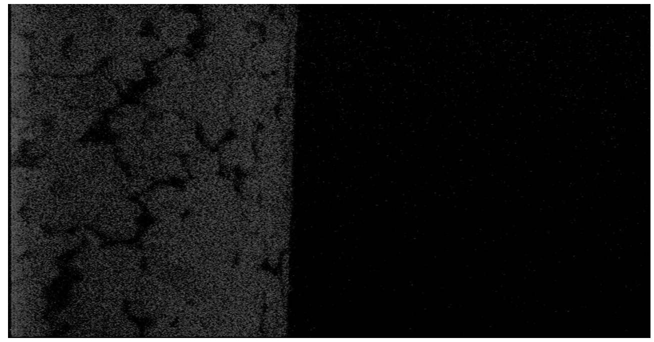


Figure 3 Pressure profiles during surface regeneration at 1200 ^{o}F.

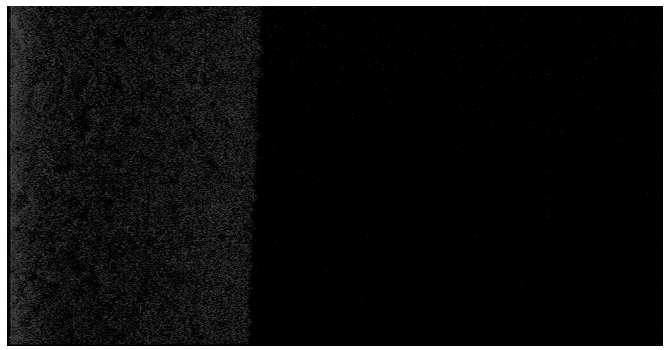
** (Pf – Pc) stands for the pressure drop across the filter (filter pressure minus chamber pressure). The number to the right refers to the regeneration cycle.





t=0 sec

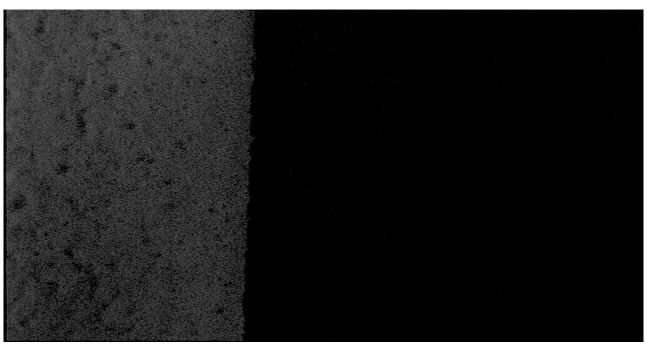
t=0.17 sec

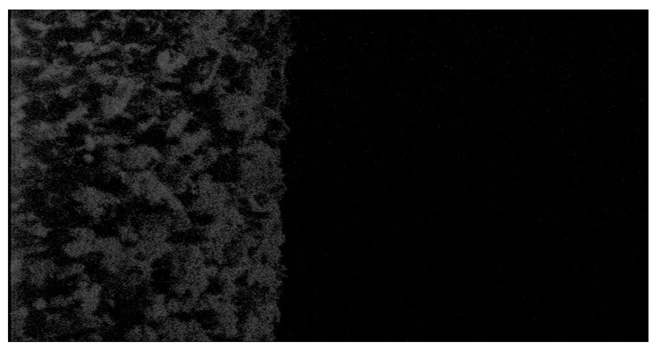


t=0.28 sec

t=0.5 sec

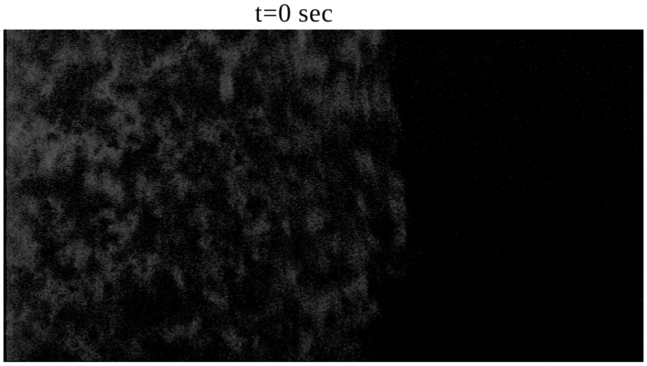
Figure 4 First Regeneration at 1100 ^{o}F.

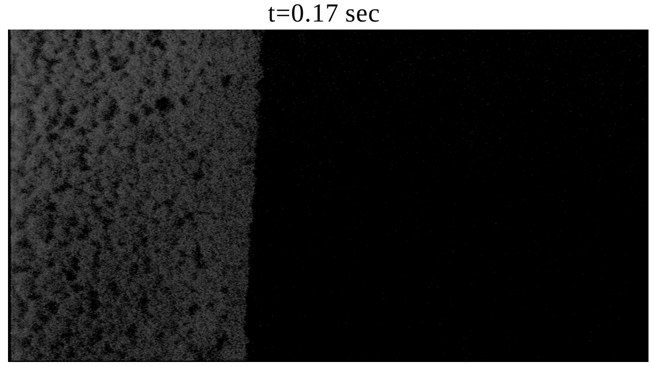




t=0 sec

t=0.17 sec

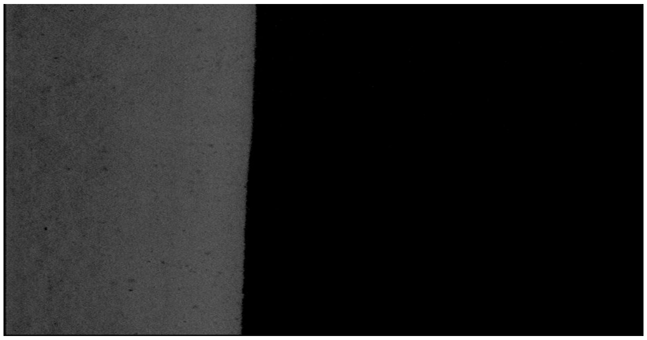




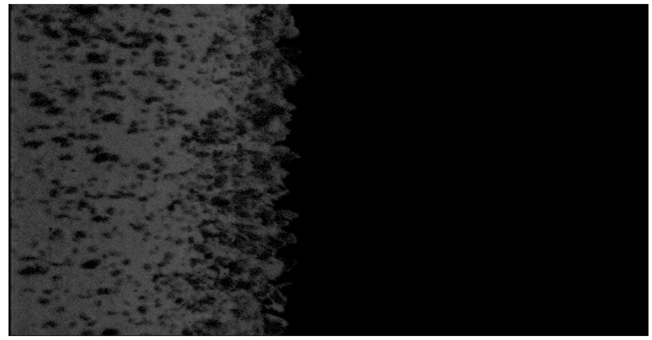
t=0.25 sec

t=0.5 sec

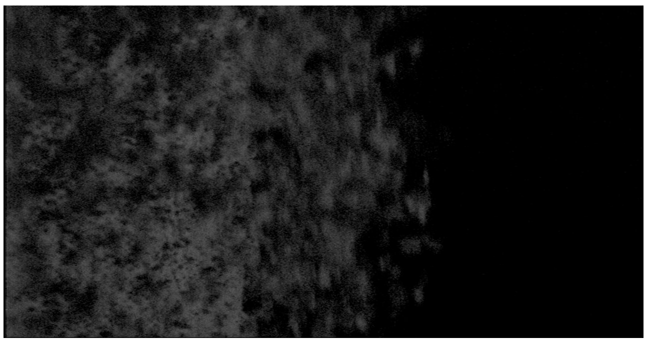
Figure 5 Second Regeneration at 1100 ^{o}F.



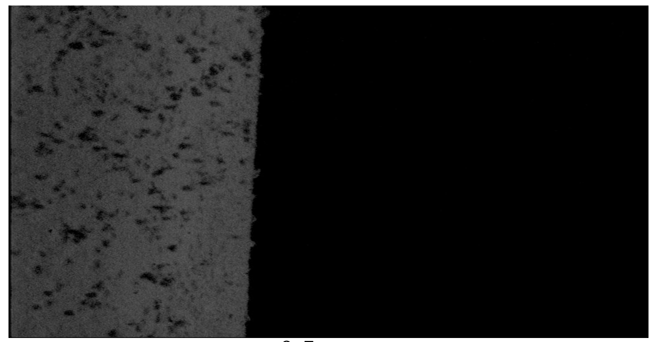
t=0 sec



t=0.17 sec

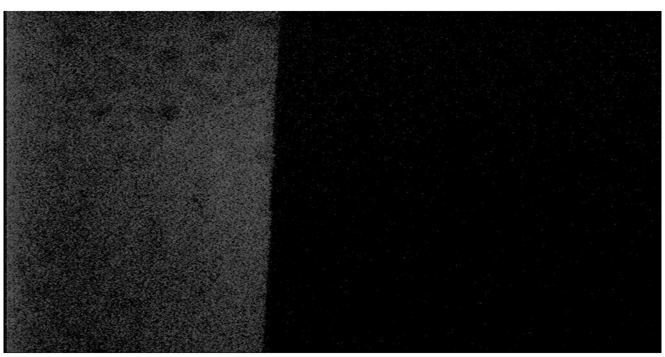


t=0.25 sec

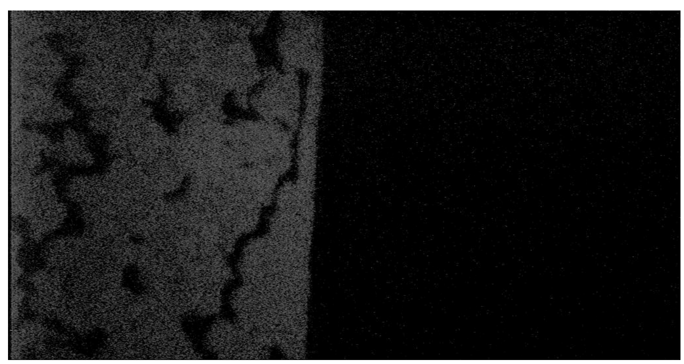


t=0.5 sec

Figure 6 First Regeneration at 1200 ^{o}F.

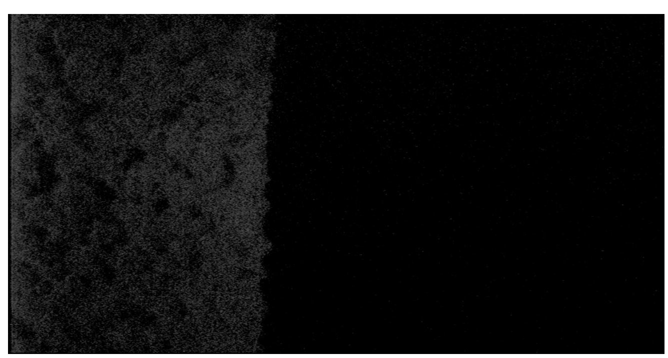


t=0 sec



t=0.17 sec

t=0.25 sec



t=0.5 sec

Figure 7 Fourth Regeneration at 1200 ^{o}F.

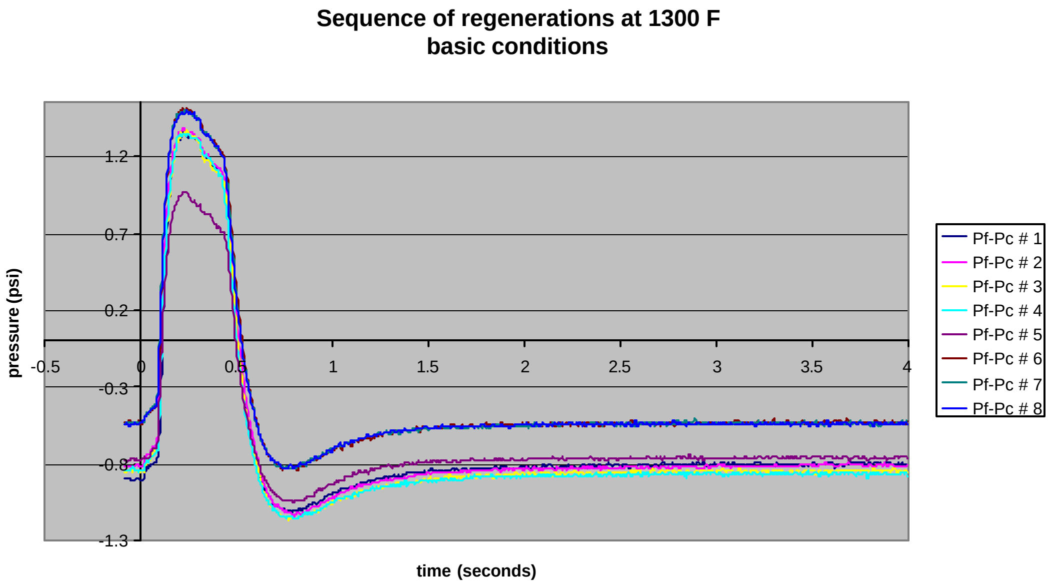
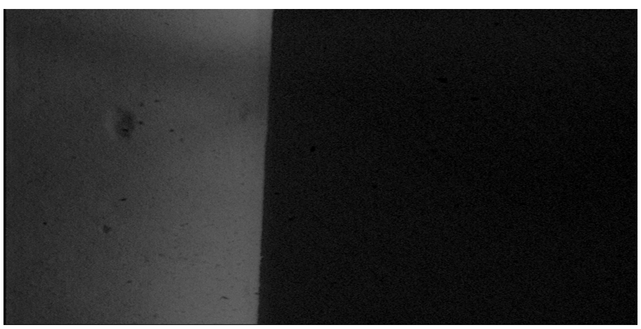
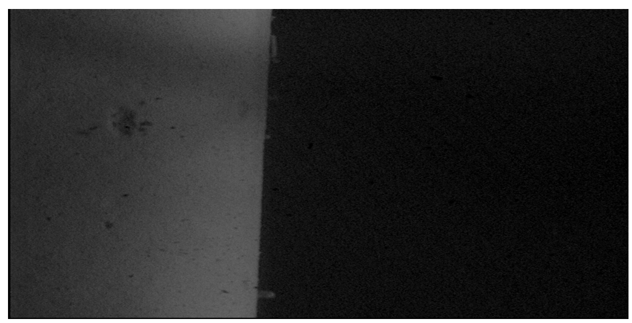


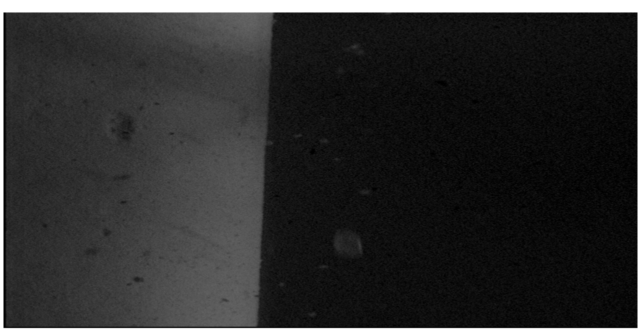
Figure 8 Pressure profiles during surface regeneration at 1300 ^{o}F.



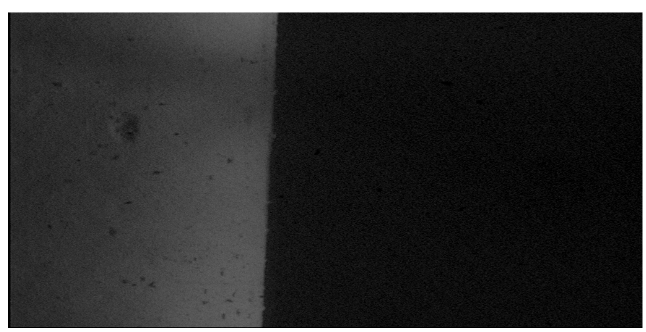
t=0 sec



t=0.21 sec

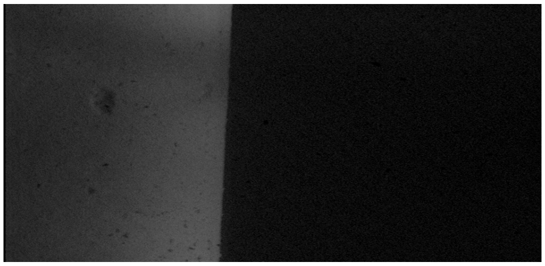


t=0.25 sec

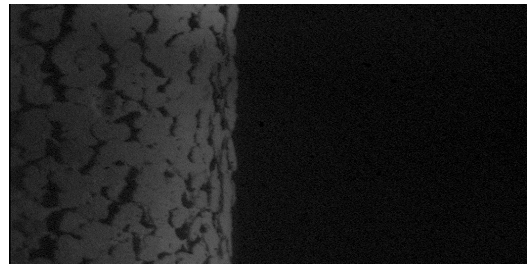


t=0.83 sec

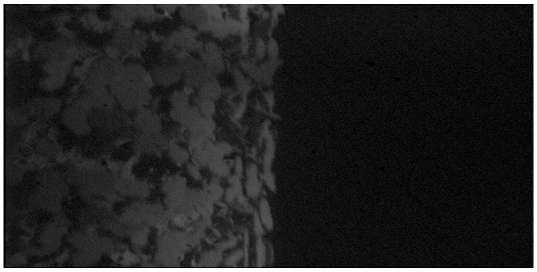
Figure 9 No Regeneration at 1300 F. 95 psi regeneration pressure
5 cm/s face velocity, 20 min build-up time. Cycle # 4.



t=0 sec

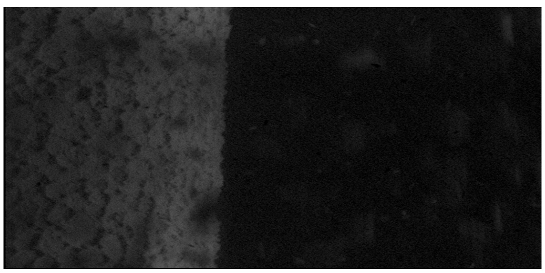


t=0.16 sec

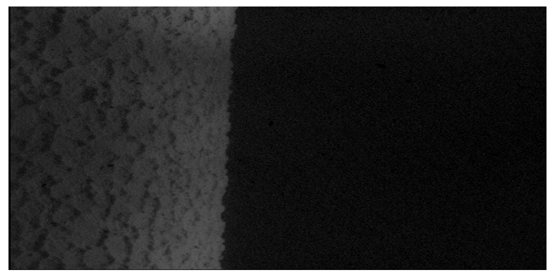


t=0.2 sec

t=0.23 sec

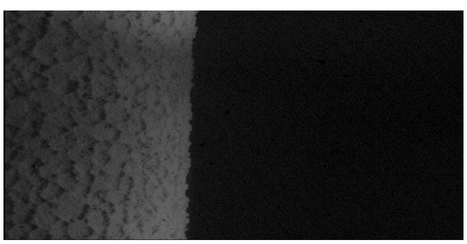


t=0.41 sec

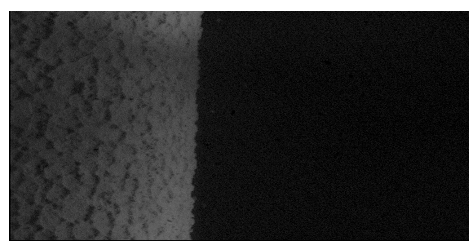


t=0.83 sec

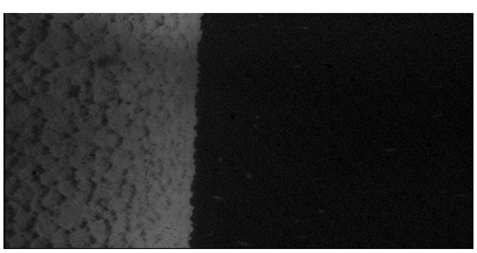
Figure 10 Surface Ash Regeneration at 1300 F. 95 psi regeneration pressure
5 cm/s face velocity, 20 min build-up time. Cycle # 5.



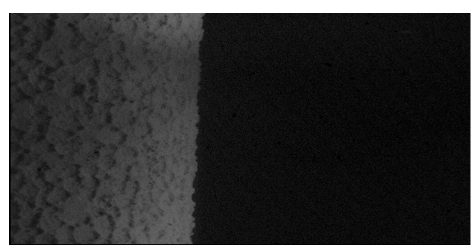
t=0 sec



t=0.21 sec



t=0.25 sec



t=0.83 sec

Figure 11 No Regeneration at 1300 F. 95 psi regeneration pressure
5 cm/s face velocity, 20 min build-up time. Cycle # 6.