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PROJECT TITLE : EXPLOSIVE FRACTURE COMMINUTION PROCESS FOR COAL CLEANING USING SUPERCRITICAL CO_2

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ABSTRACT

Current comminution techniques do not comminute selectively. They do not selectively separate or scission the carbonaceous matter from the mineral matter. Furthermore, only a few percent of the applied energy is utilized for comminution, the rest being dissipated in process inefficiencies. In this project, supercritical CO_2 is being harnessed to explosively fracture the coal into discrete minuscule particles and release the mineral matter without substantially altering the mineral matter's size. The process takes advantage of the porous fluid-permeable nature of the carbonaceous component of the coal. When the coal is flooded with supercritical CO_2, the dense fluid permeates into the pores of the carbonaceous matter in coal without affecting the mineral component. On instantaneous depressurization, the supercritical CO_2 undergoes a sudden phase change and volume expansion causing the carbonaceous matter to literally explode into discrete minuscule particles without altering or reducing the size of the mineral matter.

Chunks of Illinois No. 6 coal (IBCSP sample 1) with average particle diameters in the range of 7 to 8.2 mm was explosively shattered in a micro reactor with supercritical CO_2 using a soak time of 5 minutes and gave minute discrete particles of varying sizes. A comparison of the explosively fractured coal with a mechanically crushed sample (-100 mesh) of the same coal in a float / sink operation of Sp. Gr. 1.3 showed that the ash was evenly distributed in the sink and float fractions (11% and 8% respectively) for the mechanically crushed samples; whereas for the CO_2 fractured sample there was very little ash in the float (2%) and all the ash concentrated in the sink fraction. This suggests selective comminution of the carbonaceous fraction of the coal.

A set of of thirty explosive shattering experiments were performed by varying temperatures and pressures and the fractured coal particles were separated into 13 different fractions by sieving. The feed coal charged into the reactor had a average particle diameter of 7-8.2 mm (7000-8200 microns). Runs at 1300 psia and 40°C yielded discrete fractured coal particles , the majority of which were in the 38-605 micron range. More material was present in the smaller particle size range i.e. 38-250 microns at 40°C than at 20°C. At the lower operating pressure of 1100 psia, the lower temperature (20°C) gave more fractured material in all the fractions than at 40°C. A graphical analysis showed that at all the three operating temperatures (20, 30, 40 °C), an increase in pressure resulted in the formation of more fractured material in all the sieved fractions. This effect was very pronounced at 40°C. Operating at subcritical conditions (900 psia), gave, overall, lesser quantities of fractured material in all the fractions. Surprisingly, the run at 20°C at 900 psia gave good results in terms of the amount of fractured material found in the various fractions, especially in the smaller particle size ranges (38-605 micron). Ash analysis of the sieved fractions showed that the larger particle size fractions (700-4000 microns) contained as much as 50% of the ash.

EXECUTIVE SUMMARY

Physical coal cleaning is achieved by grinding the coal to liberate impurities that are not chemically bound and then taking advantage of specific gravity differences or surface wetting properties between the coal macerals and denser mineral impurities. It is, however, recognized that in the field of crushing and grinding only a few percent of the energy applied to the system is actually used in fracturing the coal; the remainder being dissipated in process inefficiencies., Current techniques do not comminute selectively. They grind both the ash-forming minerals, as well as the carbon fraction of the coal. They also do not selectively separate or scission the carbonaceous matter within the coal from the mineral constituents of the coal. The current comminution techniques are also limited in the degree of size reduction. In fact, for some

In this project, it is proposed to harness carbon dioxide under supercritical conditions to explosively fracture the coal into discrete minuscule particles and release the mineral matter without substantially altering the mineral matter's size. The process takes advantage of the fact that the carbonaceous fraction of coal is a porous fluid permeable solid whereas the mineral component of the coals is nonporous. When the coal is flooded with supercritical CO_2, the dense fluid permeates only into the pores of the carbonaceous matter in coal. When an instantaneous depressurization is done, the supercritical CO_2 undergoes a phase change with a sudden expansion causing the carbonaceous fraction of coal to literally explode into discrete minuscule particles without altering or reducing the size of the mineral matter of the coal. CO_2 is widely distributed in power plant stack gas, as well as in

In related work, supercritical water has been used to fracture the coal for comminution (12). Very high operating temperatures and pressures are used (T_C = 374°C and P_C = 220 Atms.), and the depressurization has, to be done at 93-149°C. Dissolution and degradation of coal components takes place at this height, temperature, and pressure.In addition, the ISGS while studying the aggregate flotation (AF) process coupled to the IITRI, explosive shattering (ES) process, report that "volatiles" produced during absorption onto the comminuted particle after shattering and causing them to aggregate. Very little beneficiation was possible with AF because the "as received" ES product tends to clump into 200-500 micron aggregates cancelling the effect of the extensive initial comminution.The CO_2 process operates near room temperatures and so these problems will not arise. Therefore, our fracturing process could potentially be coupled to the ISGS - AF process for coal cleaning.

Chunks of Illinois No.6 coal (IBCSP No. 1) with particles having average diameters in the range of 7 to 8.2 mm was selected for the explosive fracture experiments. The particle diameters were determined to serve as a control reference point for the range of coal particles sizes to be used in our experiments. In the first experimental set, the reactor was charged with CO_2 at 1050 psi , the temperature was 31°C and a soak time of five minutes was employed. When the trap door on the reactor was released resulting in instantaneous depressurization, the large coal particles were shattered into minute discrete particles of varying sizes. The fractured coal particles were subjected to a Sp. Gr. 1.3 float-sink operation and the float and sink samples were analyzed by thermogravimetric analysis (TGA). A mechanically crushed sample to -100 mesh was also subjected to the sink-float and analyzed by TGA for comparison.The key observation is the fact that in the case of the CO_2 fractured coal the ash content of the float was only 2% whereas the sink has 29% ash and in the case of the mechanically crushed sample the ash content is evenly distributed in the float and sink fractions . This supports the concept that A set of of thirty explosive shattering experiments were performed by varying temperatures and pressures (Experiment nos. CF01 to CF83, Table 2) and the fractured coal particles were separated into 13 different fractions by sieving The mesh sizes used and the corresponding particle size range in which the fractured coal particles were separated into is shown in Table 3. The feed coal charged into the reactor had a average particle diameter of 7-8.2 mm (7000-8200 microns). Table 2 gives the pressure and temperature conditions for the runs. Figure 4 shows a graphical representation of the mass percent of fractured coal particles found in the thirteen different fractions for the various explosive shattering runs (CF01 to CF83). Runs CF01-04 (same runs in triplicate) at 1300 psia and 40°C yielded discrete fractured coal particles , the majority of which were in the 38-605 micron range. Almost identical results were obtained at a lower temperature of 20°C (Runs CF21-CF23). However, a closer analysis based on the effect of temperature on the mass percent of material found in the various fractions at 1300 psia (Figure 5) showed that more material was present in the smaller particle size range i.e. 63-250 microns at

40°C than at 20°C. At the lower operating pressure of 1100 psia, the lower temperature (20°C) gave more fractured material in all the fractions than at 40°C. As can be seen from the graphs in Figure 4, this is even more prounced at 900 psia operating pressure i.e. more fractured material formed in all the fractions at 20°C than at 40°C. The graphical analysis (Figure 5) showed that, at all the three operating temperatures (20, 30, 40 °C), an increase in pressure resulted in the formation of more fractured material in all the fractions. This effect was very pronounced at 40°C. Operating at subcritical conditions (900 psia), gave, overall, lesser quantities of fractured material in all the fractions (runs CF61-63, 71-73, 81-83). Surprisingly, the run at 20°C at 900 psia (run no CF81-83) gave good results in terms of the amount of fractured material found in the various fractions, especially in the smaller particle size ranges (38-605 micron) (Figure 4). It appears that the best operating conditions are at 1300 psia and temperature of 40°C, however the run at 900psia and 20°C gave good results and needs to be reinvestigated in comparision to the higher pressure-temperature run. Ash analysis of the seived fractions from different shattering runs showed that 50% of the ash was concentrated in the larger size fractions (Figure 7). This again suggests that selective comminution of the carbonaceous fraction is taking place.

The results appear very promising. Detailed analysis & characterization of the fractured coal particles in the various fractions.is underway.

The unique potential benefits the CO_2 explosive fracture system has to

* No clumping occurs, therefore, separation of carbon from mineral matter is much more effective.

* Lower process energy inputs.

* Carbon dioxide readily and extensively penetrates the coal structure. It is likely the CO_2 diffuses into the coal along the lines of mineral inclusion as has been seen for other gases. This is important since the diffusion of reagents through solid coalmay be the rate-limiting step in many reactions. This diffusion has also been shown to

* Water-free coal product.

* Fracturing and separation can be done in the same CO_2

* Can be integerated with the CO_2-coal slurry transportation, gasification and combustion processes and contributing to better process economics of these

processes.In fact, Southwestern Public Service Co. is operating a two mile 4'-diameter test loop at its Harrington Station coal-fired power plant near Amarillo. The company has been running supercritical CO_2 through the line and even pushing batches of coal through the line

* It can also be a first pretreatment step to other carbon dioxide related cleaning technologies, namely, the LICADO process, superclean coal production by flotation with carbon dioxide process, and CO_2/water for coal beneficiation process (Brookhaven National Laboratory).

* Attractive to utilities because they produce a lot of CO_2 and can effectively use it for cleaning as well as

* The CO_2 functions as a dilutant lowering reaction zone temperatures which reduces NO_x formation

OBJECTIVES

In this project, it is proposed to harness carbon dioxide under supercritical conditions to explosively fracture the coal into discrete minuscule particles and release the mineral matter without substantially altering the mineral matter's size. This takes advantage of the fact that the carbonaceous fraction of coal is a porous, fluid permeable solid whereas the mineral component of the coal, for example, the pyrites, is nonporous and not permeable by fluids. When the coal is flooded with supercritical CO_2, the dense fluid permeates into the pores of the organic matter in coal, the inertia of which is sufficient to prevent the fluid from gradually escaping the pores during the instantaneous depressurization. When an instantaneous depressurization is done, the resulting fluid undergoes a phase change with a sudden expansion, causing the organic component of coal to literally explode. This would result in the formation of discrete minuscule carbonaceous particles without reducing the size of the mineral matter of the coal. The explosive fracture comminution by supercritical CO_2 can then be followed by separation of the fractured coal from the intact heavy mineral matter using the dense supercritical carbon dioxide

TASKS FOR THE CURRENT YEAR

Task 1	Design and fabricate a larger explosive fracturing unit.
Task 2.	Three different pressures, temperatures, and soak times will be investigated. The pressure, temperature and soak times to be studied will be based on our Phase 1 work (first year's work) with the Illinois #6 coal.
Task 3.	The fractured coal particles will be sieved into 13 fractions.
Task 4.	Size distribution analysis of the explosively-fractured product will be done. Graphs showing volumetric mean particle size as function of temperature and pressure will be generated.
Task 5.	Ash and sulfur content in the various fractions of the explosively shattered product will be obtained.
Task 6.	Reactivity of the explosively-fractured product and the feed coal will be compared by evaluating their respective oxidation rates.
Task 7.	Develop approximate design parameters.

Task 8. Integration of the explosive-shattering comminution step with coal-CO_2 slurry transportation concepts. Basic economics analysis to be performed (discussion and consultation with Southwestern Public Utility who is running a coal-CO_2 slurry pipeline at Amarillo, Texas).

INTRODUCTION AND BACKGROUND

PHYSICAL COAL CLEANING

Physical coal cleaning is achieved by grinding the coal to liberate impurities that are not chemically bound and then taking advantage of specific gravity differences between the organic matter in coal (the macerals) and denser mineral impurities. It is recognized, however, that in the field of crushing

Only several percent of the energy applied to the system is actually used in fracturing the coal; the remainder is dissipated in process

Current techniques do not comminute selectively. They grind both the ash forming minerals as well as the carbonaceous fraction of the coal. This results in the fine mineral matter being intimately mixed and dispersed into the organic phase making separations difficult.

The mechanical or grinding techniques do not selectively separate or scission the carbonaceous matter within the coal from the mineral

Current techniques are limited in the degree of size reduction.

CARBON DIOXIDE

CO_2 is widely distributed in power plant stack gas. Hundreds of millions of cubic feet of CO_2 per day is available from this source. The CO_2 content of stack gas varies from 6 to 16 percent depending on the fuel burned. Dow Chemical has announced a two-stage technology that can recovery CO_2 from flue gas streams (1). CO_2 in large amounts can be obtained from gasification plants. About 80 million cubic feet of CO_2 per day are already being produced from two SNG plants in Illinois using naphtha and NGL feedstocks. As much as 300 million cubic feet per day could be generated by some coal gasification plants. This would amount to about a trillion cubic feet over a decade. Integrated combined cycle coal gasification, second generation plants for

The large amounts of CO_2 available, especially as a part of the power plant gases and gasification plants, its unique characteristics, and potential benefits makes the explosive fracture comminution process a very attractive and viable proposition.Thus, the project is directed towards studying *Explosive Fracture Comminution Using Supercritical Carbon Dioxide* .

RELATED TECHNOLOGY

A related project using supercritical water is being developed under DOE sponsorship but this approach represents an advancement over that process and offers much more advantages. Using the supercritical water technology very high operating temperatures and pressures are required ($T_c = 374^oC$ and $P_c = 220$ Atms.), and the depressurization has to be done at 93-149°C. Dissolution and degradation of coal components takes place at this high temperature, and pressure.In addition, the Illinois State Geological Survey (ISGS) while studying the aggregate flotation (AF) process coupled to the IITRI, explosive shattering (ES) process, report that *volatiles* produced during the shattering absorb onto the comminuted particle causing them to aggregate. Very little beneficiation was possible with AF because the *as received* ES

SUPERCRITICAL CARBON DIOXIDE TECHNOLOGY

The CO_2 process operates near room temperatures and so the problems discussed earlier will not arise. Therefore, our fracturing process could potentially be coupled to the ISGS AF process for coal cleaning.

The unique potential benefits the CO_2 fracture system has to offer are:

Lower process energy inputs--operating temperature and pressure, T_c and P_c of CO_2 are 31.1^oC and 72.9 atm, respectively. All the energy is harnessed to rupture the coal particles, unlike in most mechanical energy grinding processes where much of it is dissipated in process

The CO_2-explosive fracturing process can be **integrated with the CO_2-coal slurry pipeline transportation concepts** currently being developed. In fact, plans are afoot for construction of a CO_2-coal pipeline to transport Powder River coal to the West Coast for export (2). More recently Southwestern Public Service Co. is operating a two mile 4'-diameter test loop at its Harrington Station coal-fired power plant near

Amarillo. The company has been running supercritical CO_2 through the line and even pushing batches of coal through the line (3,4). Thus, the adaptation of the CO_2-explosive fracturing process as a pretreatment step prior to transportation would result in transporting more coal than ash or mineral matter and add to the economics of the coal-CO_2 slurry transportation.

A **pumpable coal slurry with high coal loading** (80% by weight of coal) can be prepared in CO_2 media which can be fed directly into a combustion/gasification reactor, eliminating the need for dry coal handling with its associated problems. In this connection, Argonne's EES Division has shown that coal can be burned efficiently in a coal-CO_2-oxygen mixture instead of coal-air mixtures in boilers using small scale (400,000 BTU/hr. experiments) (5). The use of coal-CO_2 slurries

Integrated with other CO_2 related beneficiation technologies like the LICADO process (7), and the Brookhaven Laboratory CO_2-water beneficiation process (8). It will also enhance the capabilities of these

Work reported at the recent University Coal Research Contractors' Conference (9,10) has shown that **CO_2-treated coals are better candidates for froth flotation, bubble flotation** cleaning techniques to remove ash mineral matter from the coals than non-CO_2-

Carbon dioxide readily and extensively penetrates the coal structure (11). In fact, this has led to the advocacy of employing carbon dioxide to measure the internal area of coals. It is likely the CO_2 diffuses into the coal along the lines of mineral inclusion as has been seen for other gases (12). This is important since the diffusion of reagents through solid coal may be the rate-limiting step in many reactions. This diffusion has also been shown to cause a dimensional expansion of the

This process provides a **water free coal product.**

By using CO_2-coal slurry systems, the CO_2 can function as a diluant, lowering reaction zone temperatures which in turn **reduces NO_x**

Attractive to utilities because they produce a lot of CO_2 and can effectively use it for cleaning as well as transportation.

EXPERIMENTAL PROCEDURES

RATIONALE

A supercritical fluid (SCF) is a material heated to or beyond its critical temperature (T_c) under a pressure equal to or higher than its critical pressure (P_c) . In the supercritical state the fluids exhibit a combination of physical and chemical properties that allow them to become very powerful and unusual solvents. Under supercritical conditions the CO_2 would function as a high energy dense fluid (ca. density 0.47 g cm^{-1} . It has **higher diffusivity**, lower viscosity and lower surface tension than the liquid phase) and would permeate within the pores of the carbonaceous matter in coal, without being able to permeate the mineral matter of coal. The dense fluid mass forms a column of fluid within the pores of the coal, the inertia of which is sufficient to prevent the fluid from gradually escaping the pores during an instantaneous decompression. When instantaneous depressurization is done, the resulting fluid expands rapidly, if not instantaneously, thereby causing the carbonaceous particles to literally explode from within. This would result in the formation of

EXPERIMENTAL SETUP

The experimental setup as outlined in our proposal has been modified to incorporate a High Pressure Generator on line to deliver the CO_2 (Figure 1) . The high pressure generator is a manually operated piston screw pump designed for compressing the CO_2 to desired pressures before delivering into the reactor. The reactor is a 137 cm^3 volume micro-reactor fitted with a thermocouple controlled heating tape. The reactor is encased in a fiberglass chamber which serves as a collector for the fractured coal particles. The key element in the reactor is a trap door held by a cam which comprises the **entire bottom part** of the reactor. Turning the cam past its set point would abruptly release the trap door resulting in a instant depressurization of the reactor. The releasing of the entire bottom part of the reactor and the discharging of the coal into a large collection chamber **ensures** that the coal fracture is a result of explosive forces from within the particles (due to the CO_2 expansion and phase change) and not because the coal was ejected like a high velocity projectile from a narrow orifice If the latter event is not prevented, then, both the carbonaceous and the mineral fractions would be fractured . 4 g of coal was charged into the reactor, which was then pressurized with CO_2 Different pressures, temperatures was investigated. Future work will include varying soak times and particle sizes.

RESULTS AND DISCUSSION

Chunks of Illinois No.6 coal (IBCSP No. 1) with particles having average diameters in the range of 7 to 8.2 mm was selected for the explosive fracture experiments. The particle diameters were determined to serve as a control reference point for the range of coal particles sizes to be used in our experiments. The particle diameters were calculated using the equation $d^3{}_p$ = average weight / 0.166 pi * density which necessarily assumes that the particles are spheres.

In the first experimental set, the reactor was charged with CO_2 at 1050 psi , the temperature was 31°C and a soak time of five minutes was employed. When the trap door on the reactor was released resulting in instantaneous depressurization, the large coal particles were shattered into minute discrete particles of varying sizes (See Figure 2). The fractured coal particles were subjected to a Sp. Gr. 1.3 float-sink operation and the float and sink samples were analyzed by thermogravimetric analysis (TGA). A mechanically crushed sample to -100 mesh was also subjected to the sink-float and analyzed by TGA for comparison. Table 1 shows the results

The key observation is the fact that in the case of the CO_2 fractured coal the ash content of the float was only 2% whereas the sink has 29% ash and in the case of the mechanically crushed sample the ash content is evenly distributed in the float and sink fractions (See Figure 3). This supports the concept that the supercritical CO_2 is fracturing only the carbonaceous fraction while leaving the mineral matter intact i.e selective liberation of mineral matter.

A set of of thirty explosive shattering experiments were performed by varying temperatures and pressures (Experiment nos. CF01 to CF83, Table 2) and the fractured coal particles were separated into 13 different fractions by sieving The mesh sizes used and the corresponding particle size range in which the fractured coal particles were separated into is shown in Table 3. The feed coal charged into the reactor had a average particle diameter of 7-8.2 mm (7000-8200 microns). Table 2 gives the pressure and temperature conditions for the runs. Figure 4 shows a graphical representation of the mass percent of fractured coal particles found in the thirteen different fractions for the various explosive shattering runs (CF01 to CF83). Runs CF01-04 (same runs in triplicate) at 1300 psia and 40°C yielded discrete fractured coal particles , the majority of which were in the 38-605 micron range. Almost identical results were obtained at a lower temperature of 20°C (Runs CF21-CF23). However, a closer analysis based on the effect of temperature on the mass percent of material found in the various fractions at 1300 psia (Figure 5) showed that more material was present in the smaller particle size range i.e. 63-250 microns at 40°C than at 20°C. At the lower operating pressure of 1100 psia, the lower temperature (20°C) gave more fractured material in all the fractions than at 40°C. As can be seen from the graphs in Figure 5, this is even more prounced at 900 psia operating pressure i.e. more fractured material formed in all the fractions at 20°C than at 40°C. The graphical analysis (Figure 5) showed that, at all the three operating temperatures (20, 30, 40 °C), an increase in pressure resulted in the formation of more fractured material in all the fractions. This effect was very pronounced at 40°C. Operating at subcritical conditions (900 psia), gave, overall, lesser quantities of fractured material in all the fractions (runs CF61-63, 71-73, 81-83). Surprisingly, the run at 20°C at 900 psia (run no CF81-83) gave good results in terms of the amount of fractured material found in the various fractions, especially in the smaller particle size ranges (38-605 micron) (Figure 4). It appears that the best operating conditions are at 1300 psia and temperature of 40°C, however the run at 900psia and 20°C gave good results and needs to be reinvestigated in comparision to the higher pressure-temperature run. Figure 6 gives a comparison of the mass percent of fractured particles found in different size fractions for a series of explosive shattering runs.

Ash analysis of all the sieved fractions from the different explosive shattering runs were performed by Thermogravimetric analysis (TGA). Table 4 gives the ash content found in the various particle size fractions. As can be seen, as much as 42% of the ash is concentrated in the large particle size fractions (1000-4000 microns).

CONCLUSIONS

Coal particles with average particle diameters in the range of 7 to 8.2 mm was explosively shattered in a micro reactor with supercritical CO_2 using a soak time of 5 minutes and gave minute discrete particles of varying sizes.

TG analysis of the sink and float fractions of CO_2 fractured vs mechanically ground coal particles revealed that the CO_2 fracturing resulted in selectively shattering carbonaceous matter in coal leaving mineral matter intact.

The fractured coal particles have been separated into thirteen different size ranges and the percent weight distribution in them determined. An estimate of the mean particle size of the fractured grains in these fractions has been made. The effect of temperature and pressure on the amount of fractured material formed in the various size fractions, has been established.

It appears that the best operating conditions are at 1300 psia and temperature of 40°C, however the run at 900psia and 20°C gave good results and needs to be reinvestigated in comparision to the higher pressure-

Ash analysis of the seived fractions from different shattering runs showed that 50% of the ash was concentrated in the larger size fractions. This again suggests that selective comminution of the carbonaceous fraction is taking place.

Supercritical conditions results in much better comminution than subcritical conditions.

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TABLE 1
TG Analysis of Float and Sink Fractions of Fractured & Mechanically Crushed Coal

	CO_2 Fracture		Mechanically Crushed	
Sample	Float (%)	Sink (%)	Float (%)	Sink (%)
Water	1.52	1.52	2.54	2.32
Volatiles	45.13	35.82	42.25	41.41
Fixed Carbon	49.88	33.31	46.38	43.96
Ash	2.06	29.04	8.48	11.85

TABLE 2

COAL SHATTERING EXPERIMENTS

Code	Temp (C)	Pressure (psig)	Shattering	Sieving into 13 Fractions
CF01	40	1300	done	done
CF02	40	1300	done	done
CF03	40	1300	done	done
CF04	40	1300	done	done
CF11	30	1300	done	done
CF12	30	1300	done	done
CF13	30	1300	done	done
CF14	30	1300	done	done
CF21	20	1300	done	done
CF22	20	1300	done	done
CF23	20	1300	done	done
CF31	40	1100	done	done
CF32	40	1100	done	done
CF33	40	1100	done	done
CF41	30	1100	done	done
CF42	30	1100	done	done
CF43	30	1100	done	done
CF51	20	1100	done	done
CF52	20	1100	done	done
CF53	20	1100	done	done
CF54	20	1100	done	done
CF61	40	900	done	done
CF62	40	900	done	done
CF63	40	900	done	done
CF71	30	900	done	done
CF72	30	900	done	done
CF73	30	900	done	done
CF81	20	900	done	done
CF82	20	900	done	done
CF83	20	900	done	done

TABLE 3
Particle Size/Mesh Used for Fractionation of Fractured Coal Particles

MESH SIZE	PARTICLE SIZE (MICRONS)	AVERAGE
5-7	4000-2800	3400
7-9	2800-2000	2400
9-12	2000-1400	1700
12-16	1400-1000	1200
16-25	1000-710	855
25-35	710-500	605
35-45	500-325	428
45-60	355-250	303
60-80	250-180	215
80-120	180-125	153
120-170	125-90	108
170-230	90-63	77
230	63-0	38

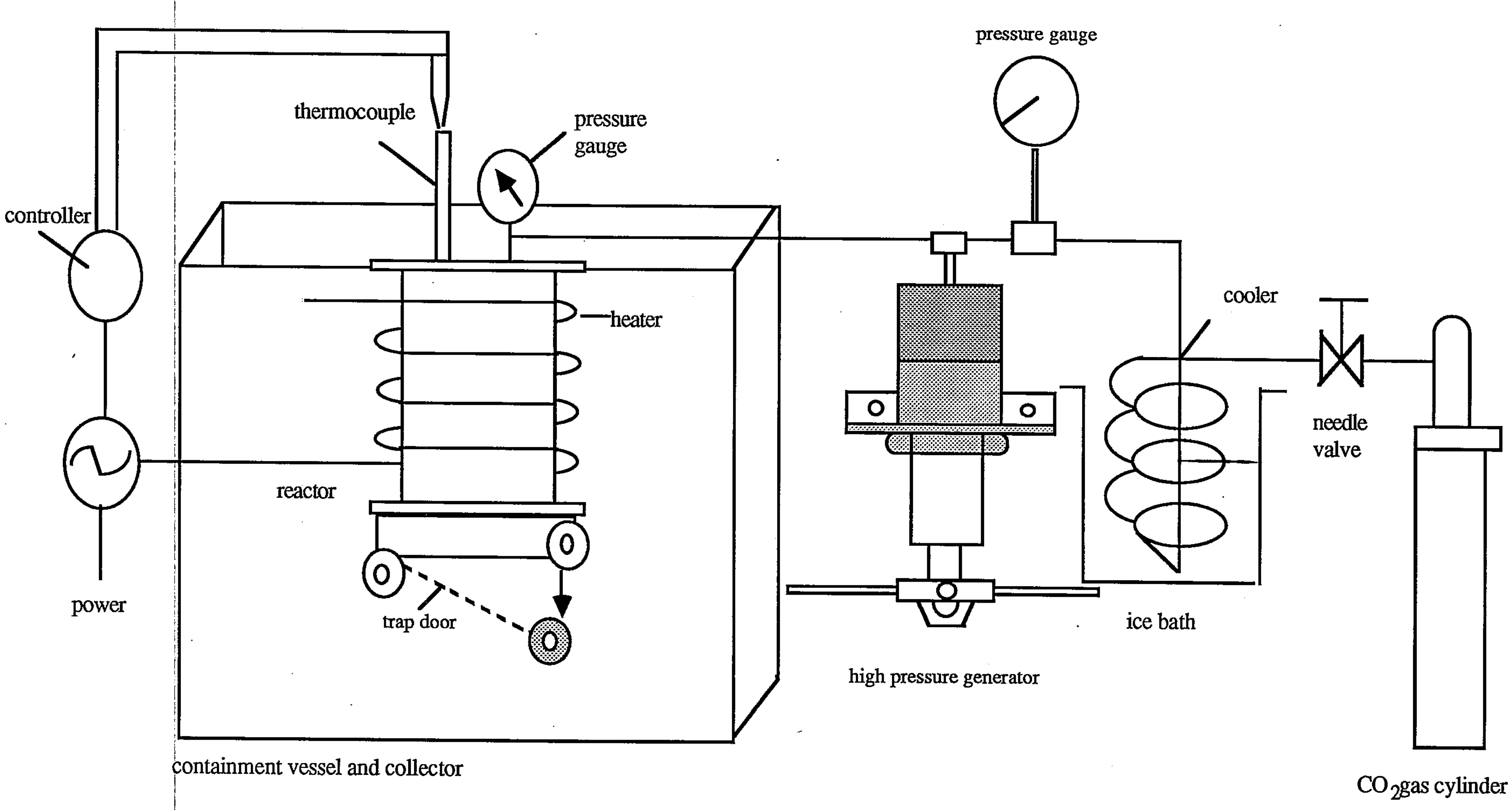


Figure 1. Experimental Setup for the Explosive Fracture Comminution of Coal Using Supercritical Calrbon Dioxide

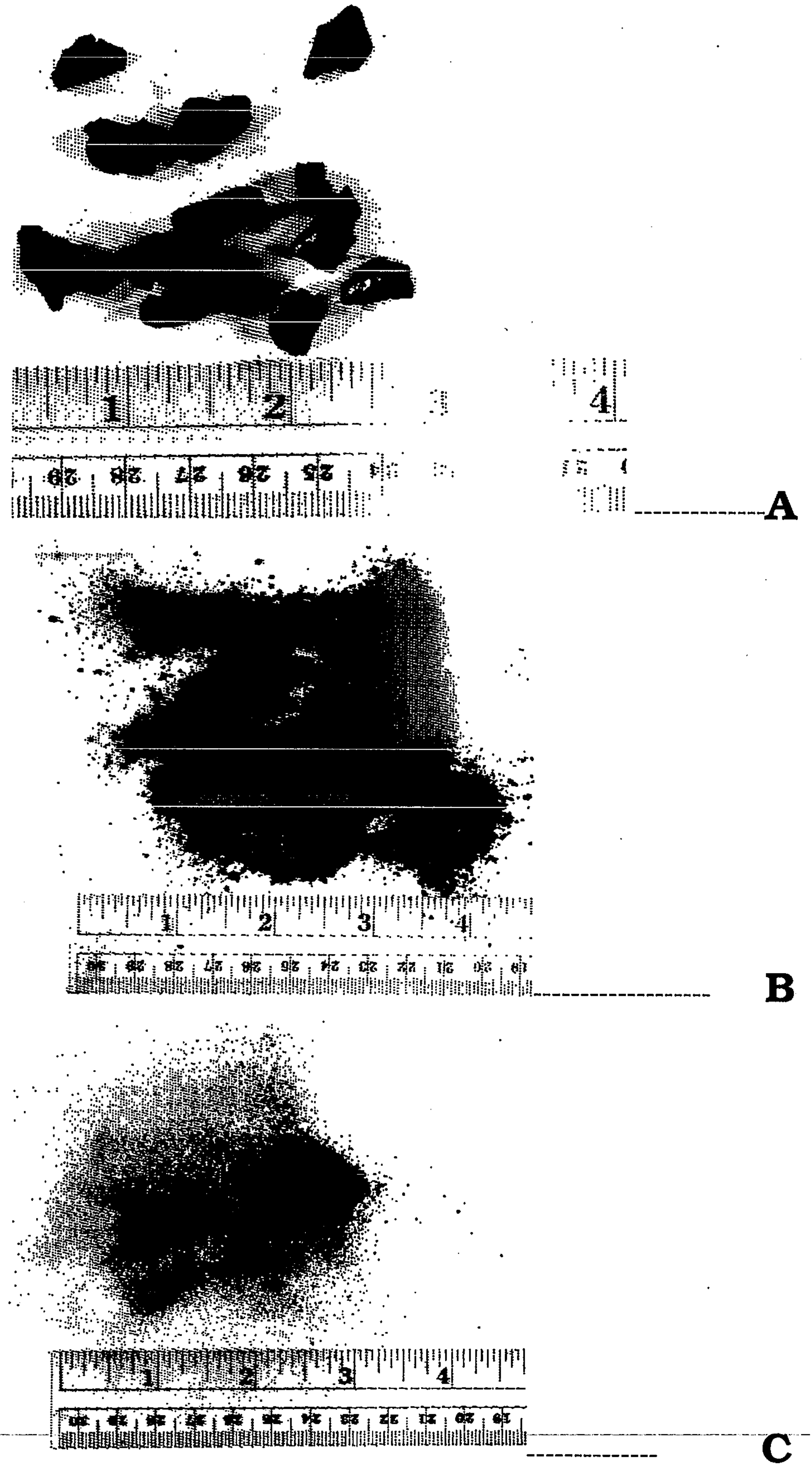


Figure 2. A) Starting coal particles. B&C) Fractured coal particles--different particle sizes

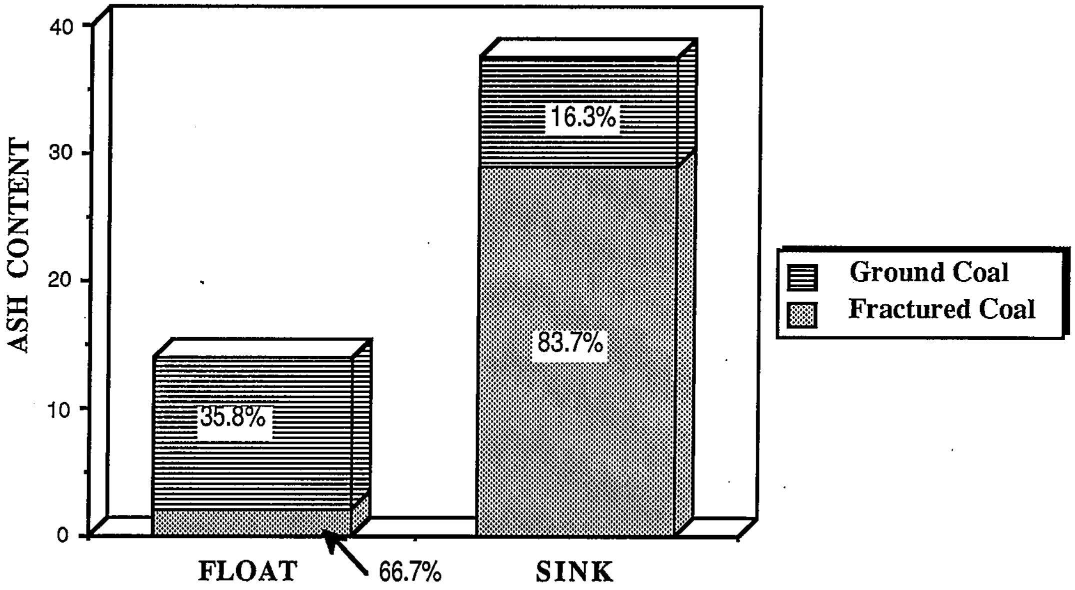
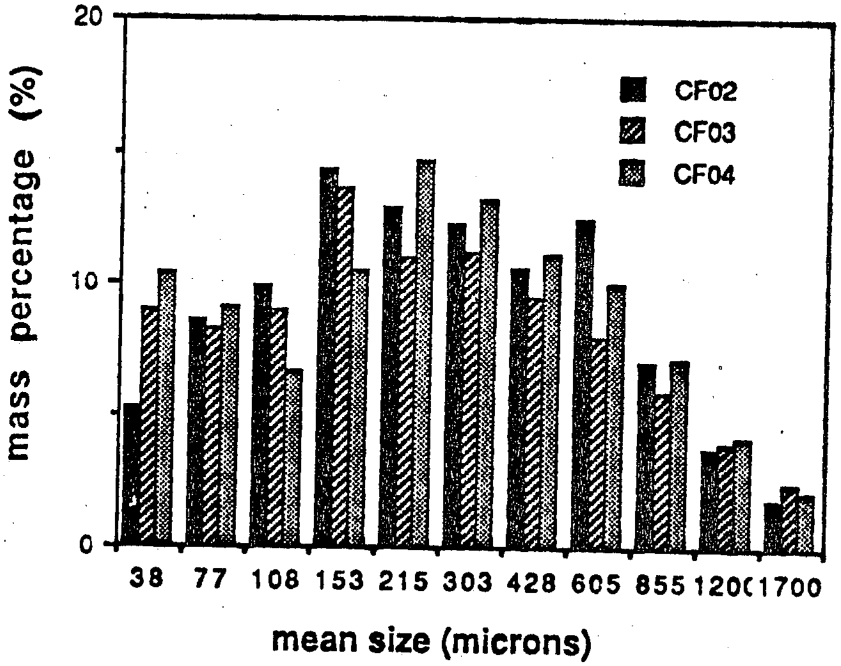
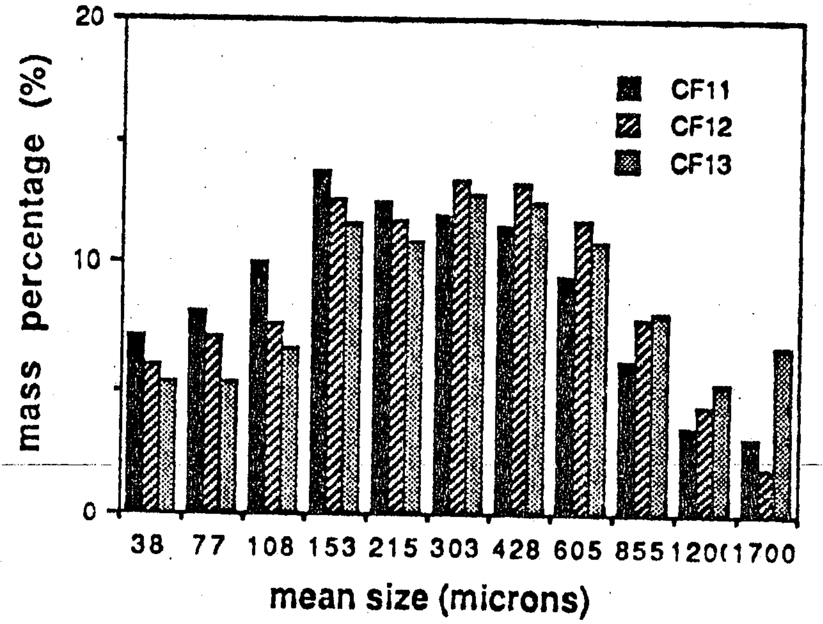


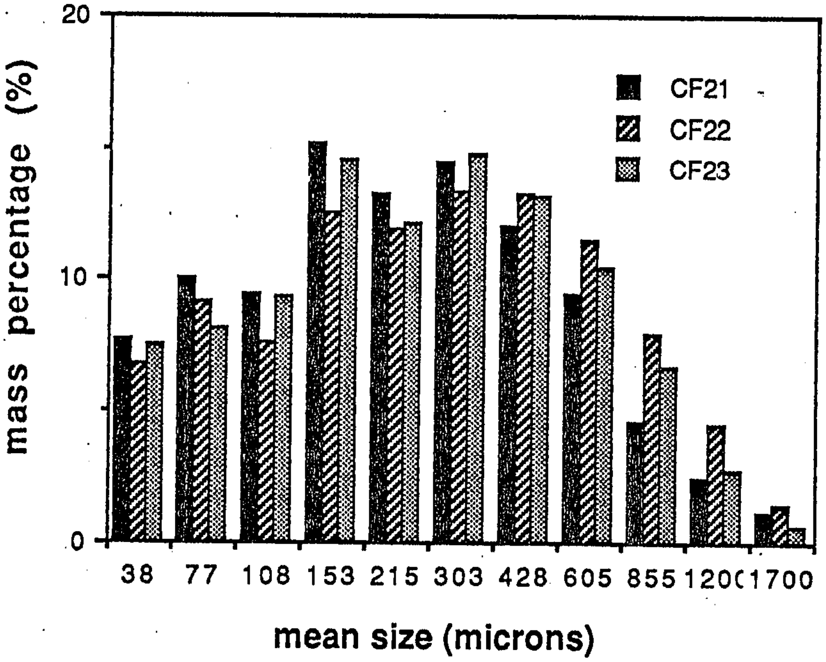
Figure 3. Ash Content of Float & Sink Fractions from Fractured and Mechanically Ground Coal

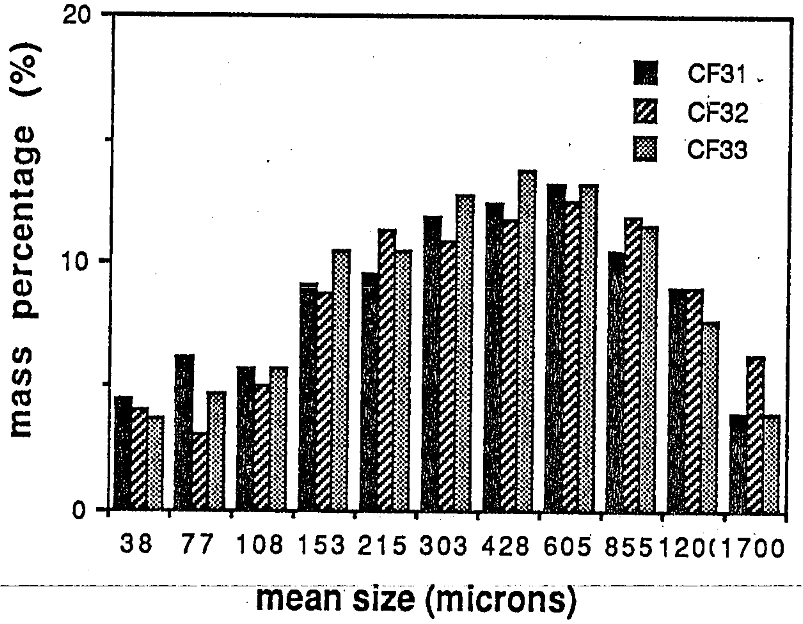
FIGURE 4

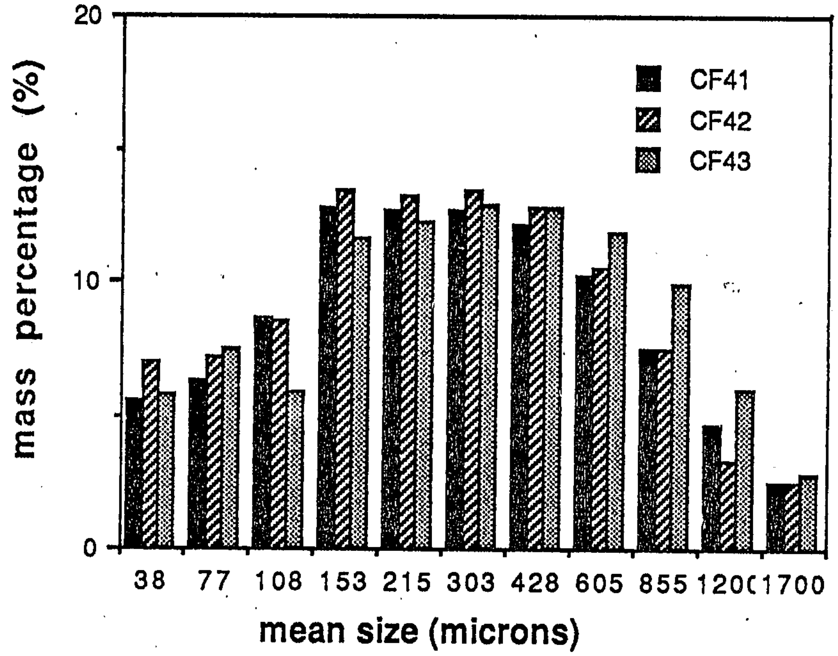
GRAPHS SHOWING THE MASS PERCENT OF FRACTURED COAL PARTICLES IN THE VARIOUS SIEVED FRACTIONS FOR ALL THE EXPLOSIVE SHATTERING RUNS

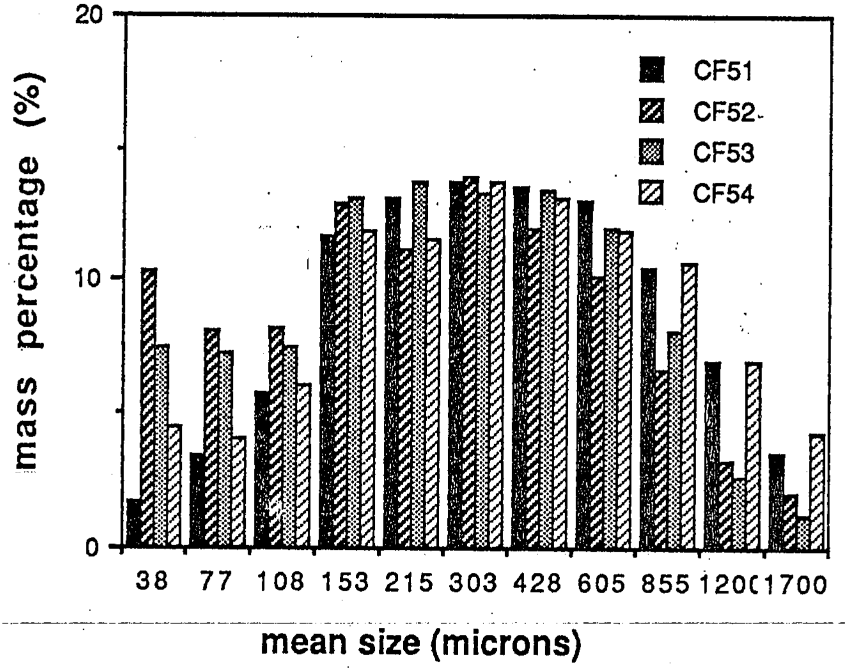

20
10
0
mass percentage (%)
CF02
CF03
CF04
38
77
108
153
215
303
428
605
855
120(
1700
mean size (microns)

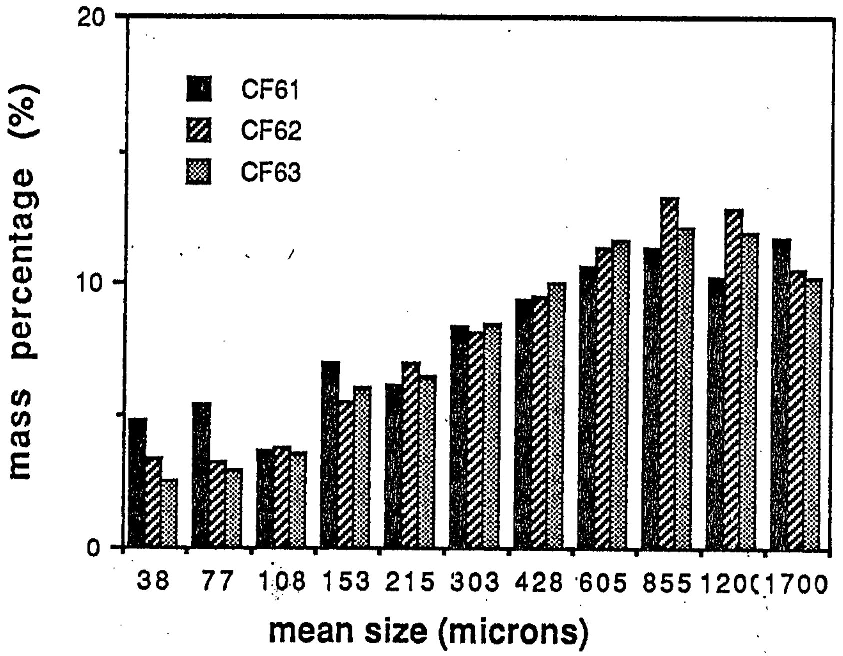

20
10
0
mass percentage (%)
CF11
CF12
CF13
38
77
108
153
215
303
428
605
855
120(
1700
mean size (microns)

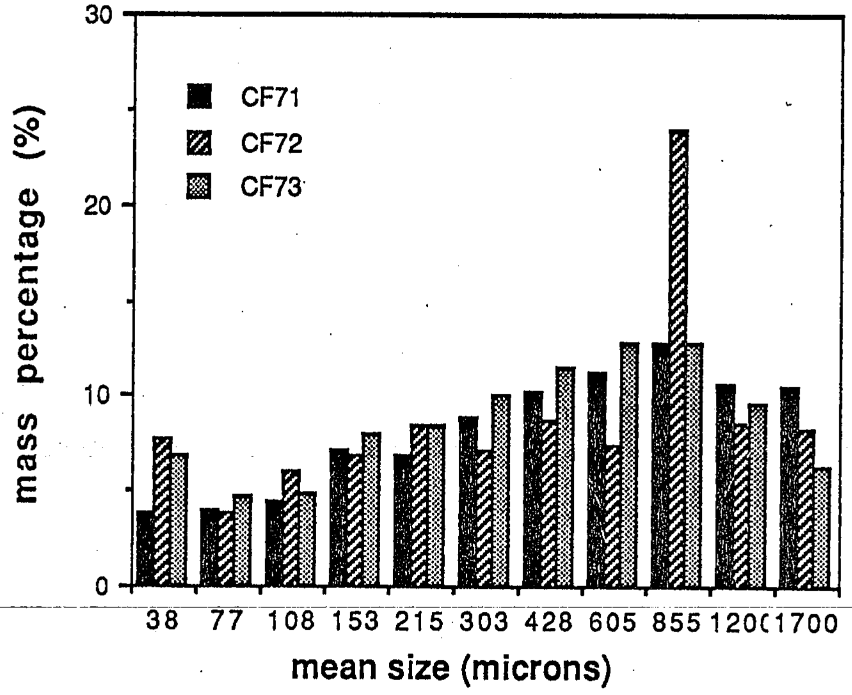

20
10
0
mass percentage (%)
CF21
CF22
CF23
38
77
108
153
215
303
428
605
855
1200
1700
mean size (microns)


20
10
0
mass percentage (%)
CF31
CF32
CF33
38
77
108
153
215
303
428
605
855
1200
1700
mean size (microns)


20
10
0
mass percentage (%)
CF41
CF42
CF43
38
77
108
153
215
303
428
605
855
120(
1700
mean size (microns)


20
10
0
mass percentage (%)
CF51
CF52
CF53
CF54
38
77
108
153
215
303
428
605
855
120(
1700
mean size (microns)


CF61
CF62
CF63
mass percentage (%)
0
10
20
38
77
108
153
215
303
428
605
855
1200
1700
mean size (microns)


CF71
CF72
CF73
mass percentage (%)
0
10
20
30
38
77
108
153
215
303
428
605
855
1200
1700
mean size (microns)

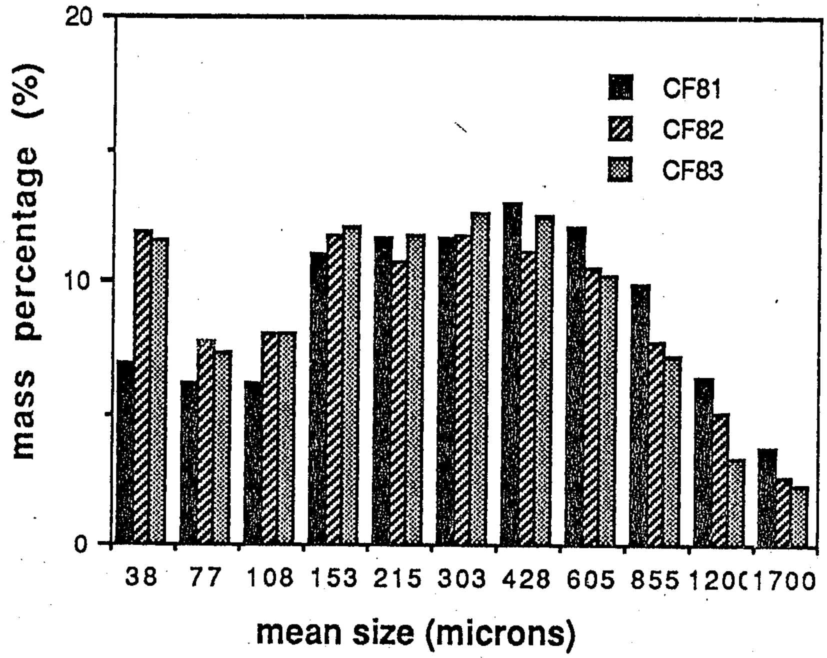
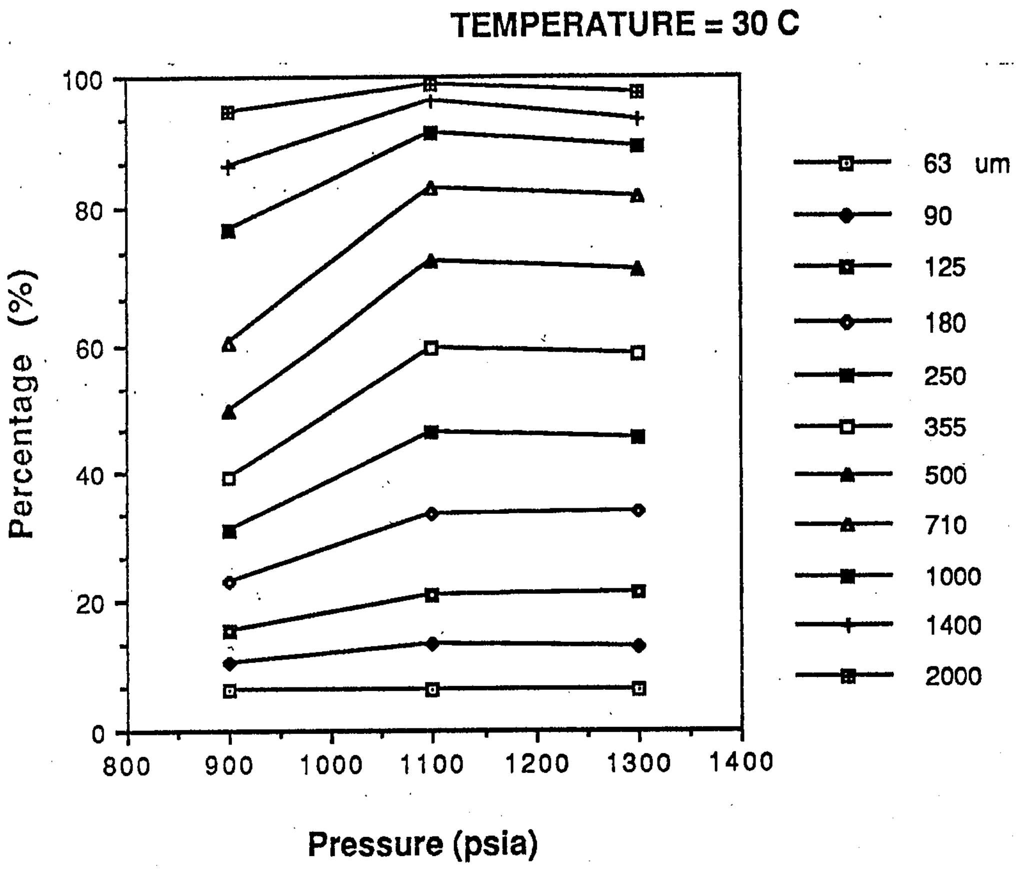
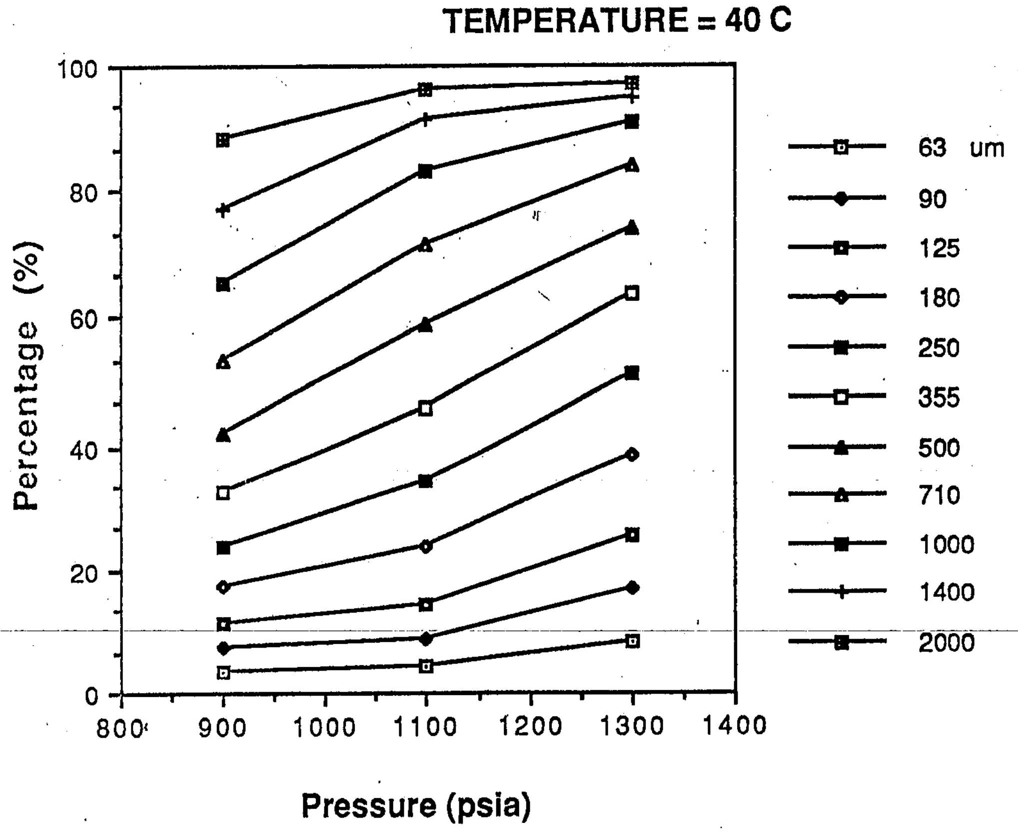
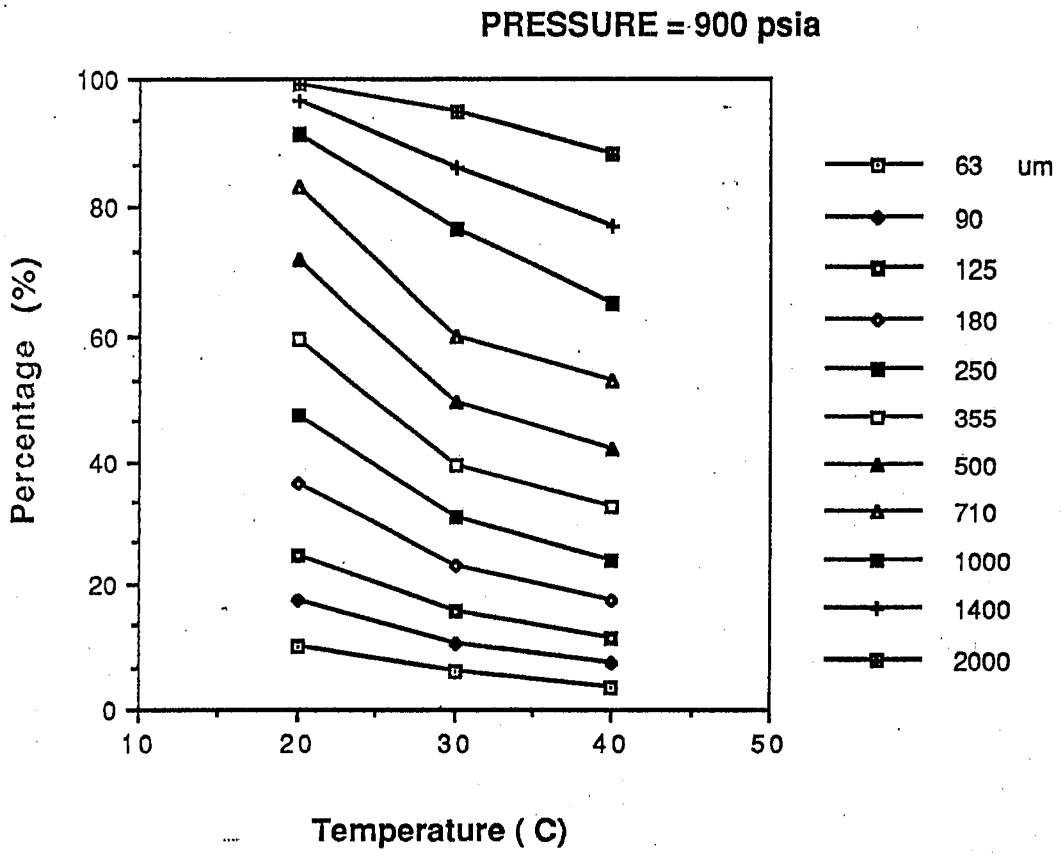

20
10
0
mass percentage (%)
CF81
CF82
CF83
38
77
108
153
215
303
428
605
855
120(
1700
mean size (microns)

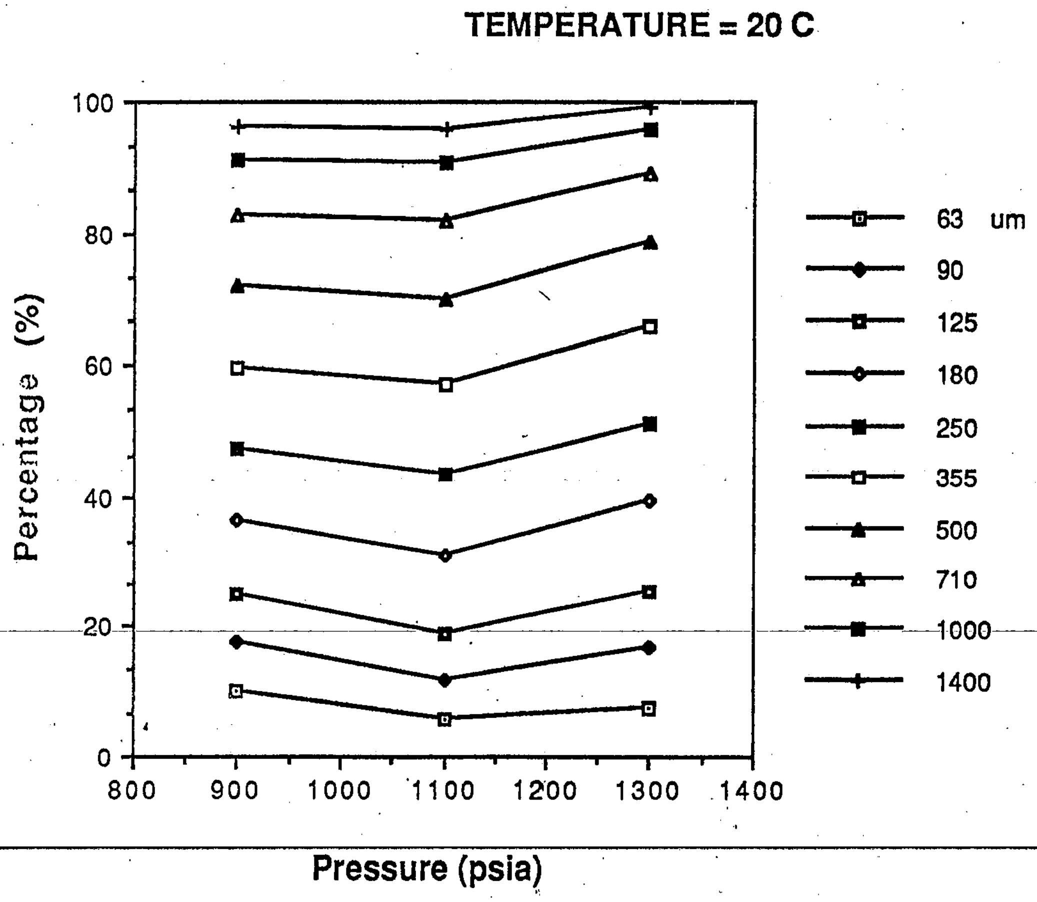
FIGURE 5

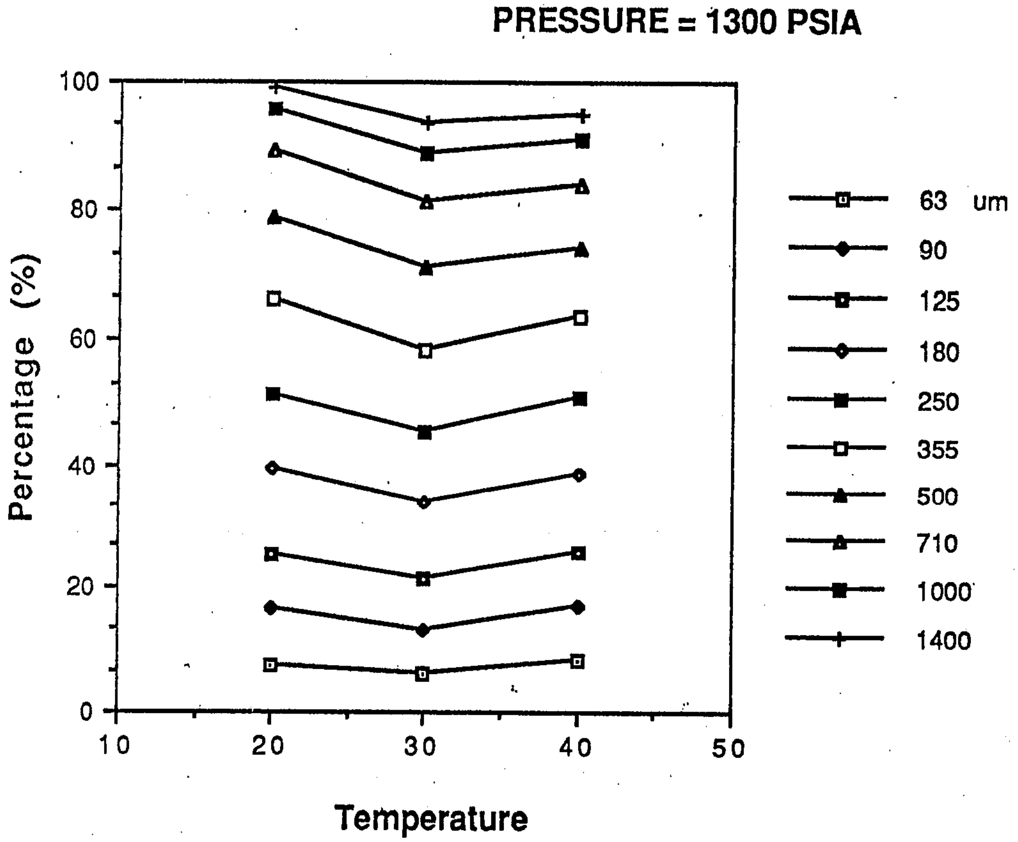
GRAPHS SHOWING THE EFFECT OF PRESSURE AND TEMPERATURE ON THE AMOUNT OF FRACTURED MATERIAL FOUND IN THE VARIOUS SIEVED FRACTIONS FOR ALL THE EXPLOSIVE SHATTERING RUNS

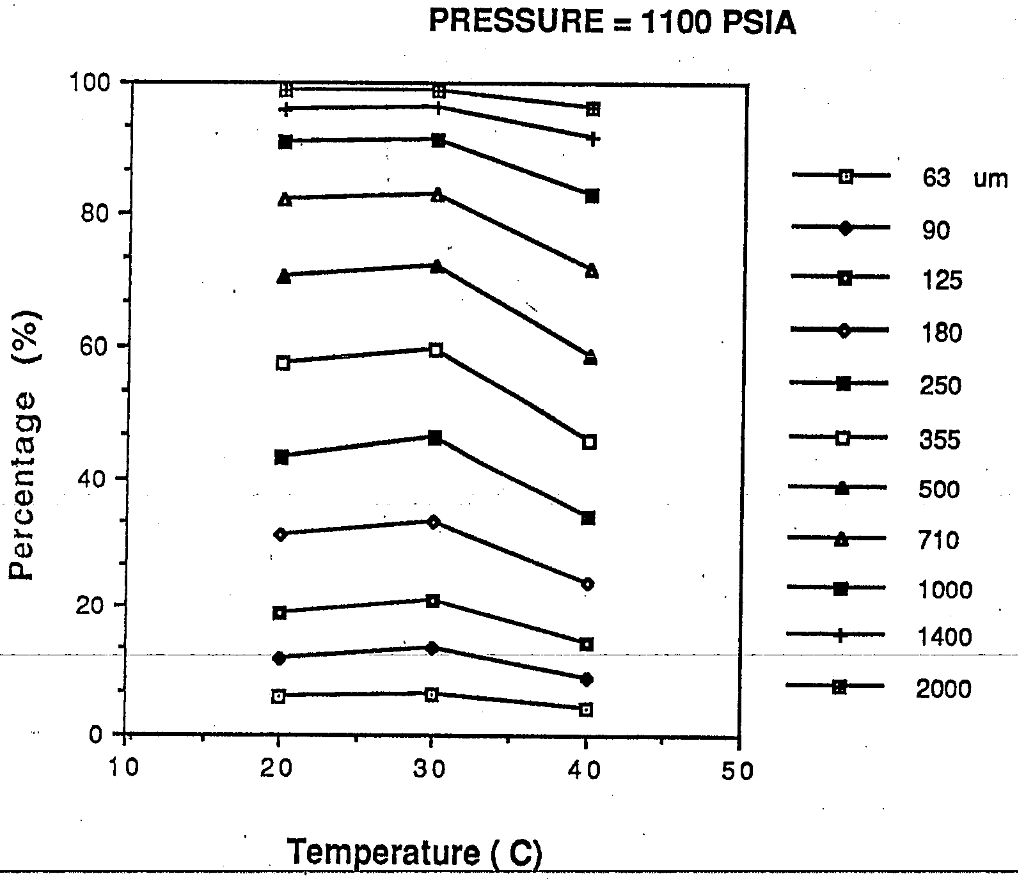

TEMPERATURE = 30 C
Percentage (%)
Pressure (psia)
0
20
40
60
80
100
800
900
1000
1100
1200
1300
1400
63 um
90
125
180
250
355
500
710
1000
1400
2000


TEMPERATURE = 40 C
Percentage (%)
Pressure (psia)
0
20
40
60
80
100
800
900
1000
1100
1200
1300
1400
63 um
90
125
180
250
355
500
710
1000
1400
2000


PRESSURE = 900 psia
Percentage (%)
100
80
60
40
20
0
10
20
30
40
50
Temperature (C)
63 um
90
125
180
250
355
500
710
1000
1400
2000


TEMPERATURE = 20 C
Percentage (%)
100
80
60
40
20
0
800
900
1000
1100
1200
1300
1400
Pressure (psia)
63 um
90
125
180
250
355
500
710
1000
1400


PRESSURE = 1300 PSIA
100
80
60
40
20
0
Percentage (%)
10
20
30
40
50
Temperature
63 um
90
125
180
250
355
500
710
1000
1400


PRESSURE = 1100 PSIA
100
80
60
40
20
0
Percentage (%)
10
20
30
40
50
Temperature (C)
63 um
90
125
180
250
355
500
710
1000
1400
2000

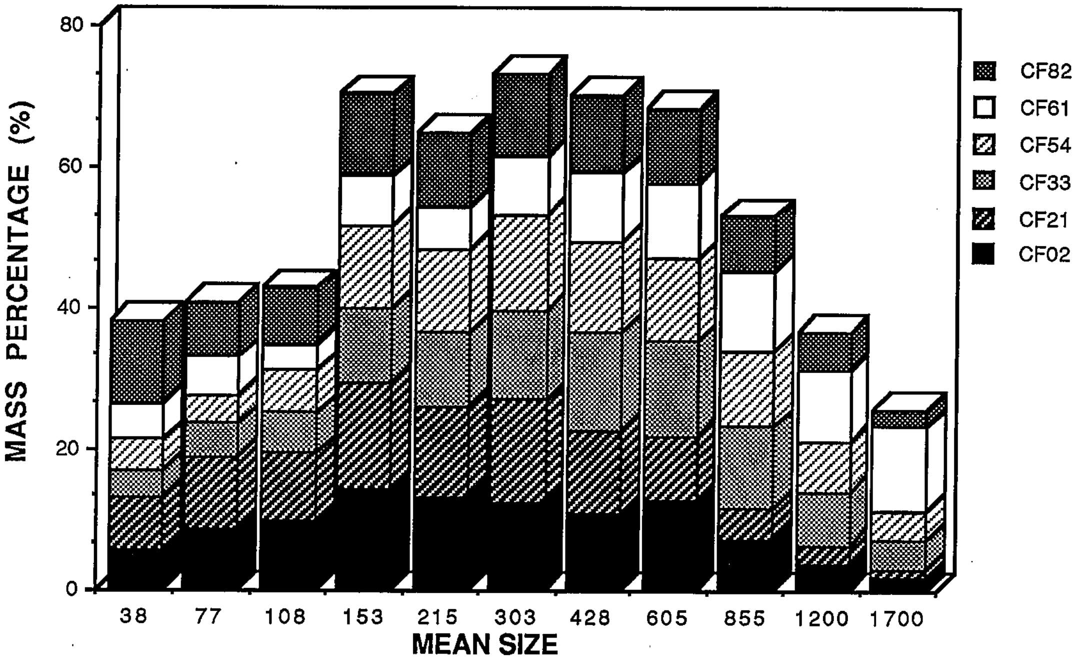


Figure 6. Comparison of the mass percent of fractured particles in different size fractions for a series of runs

PARTICLE SIZE (MICRONS)	ASH %
4000-2800	18.72
2800-2000	12.33
2000-1400	11.46
1400-1000	7.25
1000-710	7.79
710-500	7.56
500-325	6.52
355-250	7.20
250-180	5.69
180-125	5.18
125-90	5.89
90-63	4.13
63-0	3.45

42.5%

Figure 7. Ash analysis of sieved fractions