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FLUIDIZED BED COMBUSTION

of

HIGH SULPHUR COAL with VARIOUS

LIMESTONE PARTICLE SIZES

by

VLADIMIR VLADIMIROV RAZBIN

A thesis submitted to the Department of Mechanical
and Aeronautical Engineering in partial fulfillment
for the degree of Master of Engineering

CARLETON UNIVERSITY

OTTAWA, ONTARIO

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The undersigned recommends to the Faculty of Graduate Studies and Research, acceptance of the thesis: Fluidized Bed Combustion of High Sulphur Coal with Various Limestone Particle Sizes, submitted by V. V. Razbin, in partial fulfillment of the requirements for the Degree of Master of Engineering.

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Abstract

Combustion trials to explore the effect of limestone particle size on sulphur retention in a Fluidized Bed Combustion (FBC) unit were performed at CANMET Research Laboratories of Energy Mines and Resources. A pilot scale FBC combustor was used during the testing. High-sulphur Eastern Canadian coal (Devco Prince) and three size ranges of high-calcium limestone (Havelock limestone) were utilized. A total of 28 tests were completed. The fluidizing velocity was varied from 1.2 m/sec to 3 m/sec, excess oxygen in the flue gas was maintained at 3.6% (corresponding to 20% excess air) and the temperature in the combustor was maintained at 850 deg. C. A cyclone ash separator was used to capture elutriated material from the bed. For some of the tests, this material was reinjected back into the combustor, while for the remainder, it was collected in drums. Reinjection dramatically improved the sulphur retention as well as the combustion efficiency. For one of the limestone size ranges, limestone consumption was reduced by half when recycle was employed compared with similar tests with no recycle.

New equations correlating sulphur capture as a function of calcium to sulphur mole ratio (Ca/S) are proposed for Devco Prince coal and Havelock limestone for tests with and without reinjection of cyclone ash.

Combustion efficiency for tests with no reinjection was as high as 98% while for tests with reinjection was as high as 99.7%. No correlation between limestone size and combustion efficiency was observed.

The effect of prolonged operation on various parameters such as sulphur capture, fluidization, bed inventory and combustion characteristics were studied in two 24 hour tests and found to be

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V. Razbin

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NOMENCLATURE

- A — CROSS SECTION AREA (m)
- Ar — ARCHIMEDES NUMBER
- Cp — SPECIFIC HEAT OF GAS
- $\bar{D}_p$ — MEAN PARTICLE DIAMETER (m)
- dpi — REPRESENTATIVE PARTICLE DIAMETER FOR i-th SIZE FRACTION (m)
- Hmf — BED HEIGHT AT MINIMUM FLUIDIZATION (m)
- Kg — THERMAL CONDUCTIVITY OF GAS
- M — TOTAL MASS OF SOLIDS IN THE BED (kg)
- Pr — PRANDLE NUMBER = $C_p \times \mu / K_g$
- Re — REYNOLDS NUMBER = $U \bar{D}_p \rho / \mu$
- Re mf — REYNOLDS NUMBER at MIN. FLUIDIZATION = $\rho \bar{D}_p U_{mf} / \mu$
- Tb — TEMPERATURE OF THE BED (deg C)
- Tw — TEMPERATURE OF THE WALL (deg C)
- U — SUPERFICIAL GAS VELOCITY (m/sec)
- Umf — SUPERFICIAL GAS VELOCITY AT MINIMUM FLUIDIZATION (m/sec)
- Umb — SUPERFICIAL GAS VELOCITY AT MINIMUM BUBBLING (m/sec)
- Ums — SUPERFICIAL GAS VELOCITY AT MINIMUM SLUGGING (m/sec)
- Utu — SUPERFICIAL GAS VELOCITY CORRESPONDING TO ONSET OF TURBULENT FLUIDIZATION (m/sec)
- Utr — SUPERFICIAL GAS TRANSPORT VELOCITY (m/sec)
- wi — WEIGHT FRACTION OF PARTICLE IN i-th INTERVAL

GREEK SYMBOLS

- ϵ_b — EMISSIVITY OF BED PARTICLES
- ϵ_w — EMISSIVITY OF THE WALL SURFACE
- σ — STEFANS-BOLZMAN CONSTANT
- μ — FLUID VISCOSITY (kg/m sec)
- ρ_f — FLUID DENSITY (kg/m³)
- ρ_p — PARTICLE DENSITY (kg/m³)
- ϵ_{mf} — BED VOIDAGE AT MINIMUM FLUIDIZATION

I. INTRODUCTION

Fluidized bed combustion (FBC) is a result of technological development that can be traced back to the 1920's when the Winkler gasifier was developed in Germany. Modern use of fluidized bed technology started in the early 1940's with the development of catalytic cracking for production of liquid petroleum products (Zenz and Othmer, 1960 ; Zabrodsky et.al., 1966). The fluidized bed technique was extended on an empirical basis to various other processes, many of which worked successfully while others failed (Grace, 1982). Table I lists various application of fluidized beds (Yerushalmi, 1982).

From the basic principles of fluidization a variety of approaches had emerged when FBC systems had to be designed. An FBC unit can operate at atmospheric pressure or at higher pressure. As a result there are two types of designs - Atmospheric Fluidized Bed Combustion (AFBC) units and Presurized Fluidized Bed Combustion (PFBC) units.

Another division in FBC design is based on the hydrodynamics in the bed, i.e., bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). BFB utilizes larger particles (> 500 microns), lower fluidizing velocities (< 3.5 m/sec), has a discernable surface, and the solid bulk density is in the range 800 to 1600 kg/m³. A CFB unit is designed for smaller particles (< 500 microns), higher fluidizing velocity (> 4 m/sec), has no defined surface since the bed fills the volume of the combustor, and the solid bulk density is in the range 30 to 300 kg/m³ (Comparato, 1984).

TABLE 1 : APPLICATIONS OF FLUIDIZED BEDS

CHEMICAL		PHYSICAL
CATALYTIC	NON-CATALYTIC	
CATALYTIC CRACKING	ROASTING OF ORES	DRYING (coal, food, phosphates)
CATALYTIC REFORMING	(e.g. ZnS, pyrites, Cu ₂ S, CuCoS ₄)	
ACRYLONITRILE (SOHIO process)	CALCINATION (limestones, phosphates)	GRANULATION (fertilizers, pharmaceuticals)
SYNTHESIS of POLYETHYLENE (UNION CARBIDE)	INCINERATION of WASTE SOLIDS AND LIQUIDS	COATING (polymer coats on metal objects)
OXIDATION of SO ₂ to SO ₃	COKING	CLASSIFICATION
FISCHER-TROPSCH SYNTHESIS (SOUTH AFRICA)	COMBUSTION of COAL, PEAT WOOD CHIPS	MEDICAL BEDS for BURNED PATIENTS
ANILINE (hydrogenation of nitrobenzene)	FLUORINATION of UO ₂	BLENDING
	CATALYST REGENERATION	ABSORPTION (CS ₂)

Coal is the main fuel for industrial and utility FBC units. However a variety of other fuels such as wood bark, coke and garbage have been tested and utilized in FBC combustors. Major developments in FBC of coal were prompted by the user demand for combustion efficiency enhancement, stringent environmental regulations, availability of cheaper high sulphur coal and the energy crisis in the 1970's. As a result, FBC of high sulphur coals in the presence of limestone as a desulphurizing agent has emerged and established itself as an alternative to conventional methods of coal combustion. Mass application of the technology in various countries has demonstrated that the FBC boiler can be utilized to meet energy needs while burning low-grade coals in an environmentally acceptable manner (Shang, 1984). FBC offers versatility in burning a wide variety of coals, including those poor in quality that are unsuitable for use in conventional firing systems. High ash and low calorific value coals can be efficiently burned in the FBC boiler, pollutant emissions can be controlled and NOx levels are low because of low bed temperatures. All these processes occur in a single vessel, offering simplicity in the design (Comparato, 1984).

Common to all FBC systems is the combustion of fuel within a bed of particles, consisting mainly of coal ash and limestone or dolomites, suspended by an upward flow of fluidizing gas or air needed for combustion. Fig. 1 shows typical components of FBC boiler (Macansi, 1982). The combustion air from the forced draft fan is preheated and sent to the plenum chamber under the distributor plate where it is forced through bubble caps or nozzles. Solid fuel and sorbent are introduced above the distributor plate. Combustion air keeps the bed particles in suspension while the fuel is burned and flue gas produced. The in-bed heating surfaces pick up the released heat in the bed while the over-bed heating surfaces utilize the heat released in the free-board. Particulate material that has been carried over from the bed is separated from the flue gas in the cyclone and is reinjected back into the bed or discarded. Flue gas from the

cyclone can be further cooled in an economizer before being released through the stack.

As fuel and oxygen from the air react, various gaseous products such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2) and water vapour are formed. For efficient removal of SO_2 , bed temperature must be maintained in the range of 815°C to 870°C (Borgwardt, 1970) by appropriate design of the heating surfaces in the bed or by varying the rate of fuel input. Carbonaceous bed material, limestone (CaCO_3), is calcined to lime (CaO) which reacts with the SO_2 to form calcium sulphate or gypsum (CaSO_4), a waste product continuously removed during operation. Lower bed temperatures eliminate the slagging experienced with conventional pulverized-fired boilers and the thermal fixing of the atmospheric nitrogen to NO_x , which usually occurs above 1400°C (Combustion, 1981). Combustion efficiencies are high, typically in the range 92-99% (Bass and Castleman, 1984., Stover et al., 1981.) even with large fuel particles ($d > 30\text{ mm}$). High combustion efficiencies are the result of long residence time of the fuel in the bed, good mixing provided by high excess air and recycle of the cyclone material.

Heat transfer coefficients in the bed are dependent on the bed fluid dynamics, geometry arrangement of the cooling tubes, properties of the flue gas and the temperatures in the bed. High heat transfer coefficients experienced in an FBC unit are caused primarily by turbulent mixing of the particles within the bed. By comparison with conventional fuel firing systems having heating surfaces in the path of the flue gas, an FBC unit has 6 to 10 times higher heat transfer coefficients for tube surfaces in the fluidized bed (Table II) (Glicksman, 1984). This allows reduction of the volume of the FBC boiler and represents the major economic advantage of the FBC technology (Update on Advanced Fluidization Topics, 1981).

TABLE 2: APPROXIMATE VALUES
of HEAT TRANSFER COEFFICIENTS

CONDITION	h (W/M ² degC)	h (BTU/hr ft ² deg F)
TUBE SURFACE in FLUIDIZED BED	230-340	40-60
TUBE SURFACE in FLOWING GAS	35-55	6-10
LIQUID FLOW INSIDE TUBE	1400	250
BOILING INSIDE TUBE	5500	1000

SOURCE: GLICKSMAN, L.R., 1984

An FBC boiler differs from a conventional pulverized fired boiler in two major areas:

- introduction of the combustion air through nozzles at the distributor plate
- presence of sulphur sorbent in granular form in the combustion chamber

For a balanced draft unit, the combustion air pressure in the plenum chamber below the distributor plate must be high to overcome the pressure drop across the nozzles and across the bed. As a result, fan capacity has to be increased, leading to higher electrical consumption compared to pulverized fired boilers (DOE, 1979). For a medium size bubbling AFBC boiler, the windbox pressure is in the range of 1000 - 2300 mm H₂O with a fan outlet pressure of 2500 mm H₂O (Razbin and Friedrich, 1984), a three fold increase compared with conventional boilers (Combustion, 1981). Improvement in the distributor plate design can lower the pressure drop. However, to achieve good air distribution and good fluidization with different bed depths, an adequate pressure drop across the nozzles and the bed is an essential requirement. Therefore trade-off is needed in this respect.

To control the emissions of sulphur oxides from an FBC unit, limestone sorbent is added to the bed. On contact with sorbent particles the SO₂ will be chemically bound as CaSO₄, which will eventually form an impervious skin around the particle and stop any further reaction (Dutkiewicz and Naude, 1981). As a result, an additional amount of sorbent is needed if SO₂ emissions are to be maintained below the environmental limits. A mole ratio of Ca in the sorbent to S in the coal (Ca/S mole ratio) of 2 to 4 (the corresponding mass ratio of coal to limestone for high sulphur coals is approximately 4.5 : 1 to 2 : 1, see Table 7) is generally required to meet the environmental limits (Grimm, 1981). High limestone consumption leads to an increase in the operational cost of the FBC and represents the major concern of

the technology. The limestone must not only be quarried, transported, crushed and screened but large quantities of spent bed material must be disposed of (Morrison, 1982). Much of the current FBC research and development efforts are directed towards increasing the efficiency of limestone utilization, thus decreasing the quantities of limestone required. Ultimately, the goal must be a sorbent which can be regenerated and reused indefinitely. This approach was tried with limited success, and another route, i.e., finding ways of increasing the efficiency of limestone utilization, is now being pursued. Limestone utilization can be increased by careful control of the operating parameters in the FBC bed (Johnson, 1980).

Operating parameters of the FBC boiler influence the degree of limestone sulphation, and consideration must be given to these parameters during the design stage of the boiler. The parameters that must be controlled and maintained during the operation of the unit are (Highly, 1975) :

- bed fluidizing velocity

For a bubbling bed, an increase in fluidizing velocity leads to decrease of the rate of sulphation. The reason is a reduction of the contact time between the sorbent particles and the sulphur oxides in the flue gas, which tend to pass through and leave the bed with the fast moving bubbles.

- bed height

Bed height has a reverse effect on the rate of sulphation: an increase in bed height leads to an increased residence time of both the flue gas and the solids. Therefore, improvement of the sulphur dioxide removal is achieved.

- bed temperature

Bed temperature influences the sulphation and is controlled at 850 degree C for optimum limestone utilization.

- recycle of the material collected in the cyclone

Recycle of the cyclone ash increases the utilization of the limestone particles by returning them to the high temperature zone in the combustor to complete their sulphation. It also results in reduction of the particle size due to impact thus increasing the specific surface area for sulphation.

- limestone particle size

Limestone particle size determines the surface area for sulphation and is the important parameter for design and operation of an FBC unit.

The last two operating parameters were of particular interest to the Department of Energy, Mines and Resources Canada for the Summerside FBC project (Taylor and Friedrich, 1982). Supporting research was needed and the present test program fulfilled that requirement.

Combustion tests were conducted on a pilot scale FBC unit at the EMR/CANMET Energy Research Laboratories in Bells Corners. The objective of the test program was to determine the effect of limestone size on sulphur retention in the FBC unit. Additional information on the influence of the cyclone ash recycle and the fluidizing velocity on the sulphur capture was required.

A test matrix was prepared to meet the objectives. Three different limestone sizes were used during the tests, which included tests with 100% cyclone ash recycle and tests with no recycle. Three fluidizing velocities were maintained during the tests - 1.2 m/sec, 2.1 m/sec and 3 m/sec - and the excess air in the flue gas kept as close as possible to the 20% level. Constant bed level and bed temperature of 850 C were maintained. Only one fuel - sorbent combination was tested - Prince Devco coal from Nova Scotia with limestone supplied from New Brunswick's Havelock quarry. In addition, the effect of Na_2CO_3 salt on sulphation of limestone was studied.

This thesis consists of two volumes. Volume I includes Chapters I to VI while in Volume II are Chapters VII to X.

Chapter I contains the introductory remarks. The processes in the FBC unit, which include bed hydrodynamics, coal combustion, the sulphation mechanism and the heat transfer to the inbed surfaces are in Chapter II. Chapter III describes the test program and the procedures used during the testing and includes the unit description and the test matrix. The results and the discussions are presented in Chapter IV. Chapter V contains the overall conclusions and recommendations. A typical example of the recorded data and the analysis are presented in Chapter VI. The appendices, the references, the vita and the publications are in Chapters VII to X in Volume II.

II. PROCESSES in the FBC UNIT

A fluidized bed unit is a reaction chamber where several physical and chemical processes take place at the same time. They include the fluidization and bed hydrodynamics which determine the type of the FBC unit; the coal combustion and the heat release rate which influence the size of the unit; the limestone sulphation which results in reducing the sulphur emissions; and the heat transferred to the in-bed heating surfaces which produces the steam for electrical generation, for space heating or for other purposes.

II.1 Bed Hydrodynamics

In a fluidized bed unit, particles are held in suspension by the stream of gas introduced through nozzles located near the bottom of the unit. When the gas flow rate is low, the weight of the particles is higher than the lifting force created by the particle drag force from the gas stream and as a result bed particles do not move relative to one another i.e. the bed is in a packed (fixed) condition. As the air flow rate increases, the bed starts to move when the pressure drop across the packed bed equals the material weight per unit area of the bed. The minimum fluidizing velocity, U_{mf} , is a measure of the superficial gas velocity (superficial gas velocity is calculated from the gas flow rate and the cross-sectional area of the unit) at which there is a transition from a fixed bed to a fluidized bed behavior (Grace, 1982). For a given material, it is best determined experimentally in a small laboratory unit, with the vessel diameter much bigger than the diameter of the bed particles. The method essentially involves an extrapolation of the two straight line portions of a pressure - drop - vs - superficial - velocity plot (Fig. 2). If U_{mf} must be

FIG. 2

Source:
Update on
Advanced Fluidization
Topics, 1981

calculated, the following correlations are recommended (Fig. 2)
(Grace, 1982):

- for small particles i.e. when $\overline{D_p} < 3 \text{ mm}$

$$\text{Re}_{mf} = 7.5 \times 10^{-4} \text{ Ar} \quad \text{or}$$

$$U_{mf} = 7.5 \times 10^{-4} (\rho_p - \rho_f) g \overline{D_p}^2 / \mu_f \quad \text{when } (\text{Ar} < 10^3)$$

- for large particles i.e. when $\overline{D_p} > 3 \text{ mm}$

$$\text{Re}_{mf} = 0.202 \text{ Ar}^{1/2} \quad \text{or}$$

$$U_{mf} = 0.202 \sqrt{(\rho_p - \rho_f) g \overline{D_p} / \rho_f} \quad \text{when } (\text{Ar} > 10^3)$$

$$\text{where } \text{Ar} = \rho_f (\rho_p - \rho_f) g \overline{D_p}^3 / \mu_f^2$$

$$\text{and } \overline{D_p} = \frac{1}{\sum (w_i / d_{pi})}$$

and ρ_f and μ_f should be evaluated at the bed temperature. The minimum fluidizing velocity, U_{mf} , is a key parameter in characterizing the particulate material. A second important parameter is the bed voidage. At minimum fluidizing conditions E_{mf} is defined as:

$$E_{mf} = 1 - \frac{\rho_p}{\rho_p H_{mf} A}$$

where M is the total mass of solids in the bed, H_{mf} is the bed height at minimum fluidizing velocity and A is the cross-section area of the bed. E_{mf} is best determined experimentally; it typically lies in the range of 0.40 to 0.60 (Grace, 1982).

Minimum fluidizing velocity U_{mf} and the voidage at minimum fluidizing conditions E_{mf} are critical parameters of the fluidized bed. As superficial velocity is increased the bed shows different hydrodynamic behaviors as follows (Grace, 1982):

_ fixed bed - $0 < U < U_{mf}$ - superficial velocity is less than the minimum fluidizing velocity. Bed particles are quiescent and the gas flows through the interstices.

_ particulate fluidization - $U_{mf} < U < U_{mb}$ - superficial velocity is greater than the minimum fluidizing velocity but less than the minimum bubbling velocity (at which bubbles start to appear). The bed expands smoothly in a homogeneous manner with a well-defined top surface. Air pressure fluctuations below the distributor plate are very small and particle motions appear.

_ bubbling fluidization - $U_{mb} < U < U_{ms}$ - superficial velocity is greater than the minimum bubbling velocity but less than the minimum slugging velocity (slugging occurs when bubble size is equal to or greater than the diameter of the bed. For large diameter beds the slugging regime may be bypassed). Voids start to appear in the bed near the distributor plate and to grow by coalescence. Top surface is well defined and air pressure fluctuations below the distributor plate are of appreciable amplitude.

_ slugging regime - $U_{ms} < U < U_{tu}$ - superficial velocity is greater than the minimum slugging velocity but less than the minimum turbulent velocity. Voids fill most of the cross-section of the bed and the top surface rises and collapses frequently. Air pressure fluctuations below the distributor plate are

large in amplitude.

_ turbulent regime - $U_{tu} < U < U_{tr}$ - superficial velocity is greater than the minimum turbulent velocity but less than the transport velocity. Voids are small, top surface of the bed is difficult to distinguish and particle clusters move up and down above the bed. Pressure fluctuations of the fluidizing air below the distributor plate are small in amplitude.

_ fast fluidization - $U_{tr} < U$ - superficial velocity is greater than the transport velocity and particles are elutriated from the bed. The bed has no defined surface, and material is transported out of the bed and feed material streams must be added near the bottom of the bed. A hot cyclone separator provides separation of the circulating particles, which are also re-introduced near the bottom.

Flow regimes, from bubbling to fast fluidization, are characterized by good mixing of the solids. For the bubbling regime, vertical mixing tends to be more rapid than radial mixing while for turbulent and fast fluidization regimes radial mixing increases (Grace, 1982). The presence of heating surfaces in the bed has a significant influence on the solids mixing in the bed.

II.2 Coal combustion

The combustion of coal within the fluidized bed involves processes which must be considered if a FBC combustor is to be analyzed and designed properly. They are as follow:

II.2.1 - coal devolatilization or pyrolysis

A coal particle injected into the FBC unit will be heated quickly up to a temperatures where drying (at about 110 deg C) and devolatilization or thermal decomposition reactions (at about 350 deg C) will start. Further increase of particle temperature (above 400 deg C) leads to an increase of particle fine porosity and surface area as a result of the devolatilization. Different types of coal react differently in the combustor. With high volatile fuels such as lignites and sub-bituminous coals, the fine pore surface area will continue to increase with increase of the temperature up to the 500 to 600 deg C range and then will decrease substantially as the temperature is further increased to the 700 - 1000 deg C range as particle enters the plastic region (Combustion, 1981). Bituminous coals, however, enter into a plastic region at temperatures of 420-450 deg C and the surface area then shows a sharp decrease above this temperature range. Volatiles released from the inside of the coal particle form bubbles which cause a swelling and bursting of the particle; however, there is no formation of fine pore surface. A non-porous surface yields low accessibility of the interior of the coal particle to reactive gases around the particle. Following the plastic stage, resolidification takes place as the temperature increases (Combustion, 1981).

The initial pyrolysis period leads to release of H_2 , H_2O , CO , CO_2 , CH_4 , H_2S and hydrocarbon gases, while secondary devolatilization produces mainly hydrogen and methane (Kearns et. al., 1984). The devolatilization time of coal particles of 1-5 mm diameter may extend up to 20 sec (Stubington, 1980) for under-bed feed while for over-bed feeding it may be longer. Observation of devolatilization of coal particles in the fluidized bed reveals that coal particles are enclosed within the volatiles bubble and generally move upward as the reaction with oxygen occurs at the bubble boundary. Downward movement occurs only after the plume-like flame has consumed the volatiles bubble supporting the particle (Pillai, 1982 ; observation during operation of FBC units at Summerside). If volatiles are still being evolved the whole process repeats itself.

11.2.2 - combustion of volatiles

Products of pyrolysis will mix and react with excess oxygen in the bed. The rate of chemical reaction is very high and as a result the controlling factor is the mode of mixing of the gases in the bed (Stubington, 1980). This leads to a requirement for a specific number and distribution of the feeding points of the coal on the bed. Various models have been proposed to predict volatiles combustion for both in-bed and for over-bed feeding. However none of them can be universally applied to the various designs of the combustors (Kearns, 1984).

11.2.3 - char combustion

Char combustion follows the pyrolysis of the coal particle and is a relatively long process compared with pyrolysis or volatiles combustion. The accepted reaction mechanism under FBC conditions is that oxygen reacts at the char surface yielding CO and no CO_2 . Carbon monoxide then reacts with the oxygen. For larger particles ($D_p > 1.00$ mm) the surface temperature is up to 150 deg C greater than the average bed temperature (Kearns, 1984) because

of the oxidation process near the particle surface (observation during operation of FBC units at Summerside). For smaller particles the surface temperature is near that of the bed because oxidation of CO occurs away from the surface of the particle (Kearns, 1984).

11.3 Sulphation Mechanism

Emissions of SO₂ from a fluidized bed unit are controlled by limestone injection in the combustor. The calcined sorbent chemically binds the SO₂ released during the combustion of the coal. The mechanism of absorption of SO₂ by CaO is not completely understood, primarily because of the interaction between physical and chemical processes occurring within the particle. The structure of the sorbent - pore and grain size- is of primary importance when considering the progress of the chemical reaction particularly because the diffusional limitation to the reaction rate dictates the degree of sulphation (Burdett, 1983). In a FBC, SO₂ reacts in presence of oxygen with calcium oxide (formed after calcination of the limestone) to form calcium sulphate:

Limitations on the rate and extent of sulphation occur because CaSO₄ has a molar volume considerably larger than either the oxide (CaO) or the parent carbonate (CaCO₃) (the molar volumes at standard conditions are : 52 cm³ per mol - CaSO₄ ; 17 cm³ per mol - CaO and 37 cm³ per mol - CaCO₃) (Weast, 1968). Absorption of SO₂ inevitably introduces restrictions on

diffusivities within the particle as a result of plugging of the pores and eventually halts the reaction. The pore and grain structure produced during the calcination

of the sorbent is a key parameter determining the utilization efficiency of the limestone. When calcination is slow, then fine pores formed from the release of CO_2 consolidate into wider pores thus increasing the capacity of the sorbent to sulphate. When calcination is rapid, then the fine pore structure freezes into place (the chemical reaction front moves rapidly away) thus decreasing the sulphation capacity of the sorbent. Different limestones calcine differently depending on their geological origin. The presence of various impurities also influences the pore formation during calcination. All those factors lead to different amount of penetration of SO_2 into the interior of the particle before pore blocking occurs (Burdett, 1983; Johnson, 1980; Kearns, 1984).

Prior to introduction into the FBC unit, to improve the pore structure treatments of limestone could be used, such as a precalcination process (heat treatment to release the carbonates), secondary heat treatment and the use of salt additives. Controlled calcination of the sorbent material prior to feeding into the bed improves the sulphation because the calcination process produces material with larger pores and as a result a higher degree of sulphation can be achieved (Ulerich et. al., 1977; Smyk et. al., 1980). Optimum calcination conditions remain specific to each sorbent and must be determined experimentally. If, after the initial calcination, limestone is heated up to 1200 C its utilization as a sulphur sorbent can further increase as a result of structural changes of the particles (Newby et.al., 1980). The addition of small quantities of inorganic salts like NaCl and Na_2CO_3 can further enhance the sulphur capture efficiency of the limestone sorbent (Yang, 1978; Smith et.

al., 1981). The salt induces structural rearrangement in limestone particles that can lead to an improved pore structure and pore distribution for better sulphation.

Each of the processes involving pretreatment of the limestone is associated with an overall increase of process complexity. For the case of salt addition, a possibility of corrosion of in-bed heating surfaces arises. This could lead to serious effects in large scale FBC units and as a result has been tried on pilot scale units only. Economic evaluation of all pretreatment processes show that benefits of reducing the limestone consumption can not be justified for mass applications in large scale FBC units (Newby, 1980).

Another factor in the sulphation process is the effect of temperature on the degree of sulphation, with maximum achieved at around 850 degrees C. This value is in disagreement, based on the reaction kinetics, with the predicted theoretical temperature of 1100 degree C for maximum sulphation and the reason for the discrepancy is not fully understood. The amount of SO₂ absorbed by a limestone particle appears to increase (because of increased mobility of the species) as the temperature is raised up to 850 C and then starts to decrease (Robert et.al., 1975). It is generally agreed that the origins of this phenomenon are chemical in nature, since the physical structure of the particle does not affect its temperature. The area of uncertainty lies in the identities of intermediate species formed during the absorption. One proposed mechanism (Burdett, 1983) favors initial oxidation of SO₂ to SO₃ according to :

followed by sulphation of calcined limestone

The formation of sulphate occurs at a rate dependent on the rate of SO_3 diffusion into the particle grains. Barriers to diffusion are set up by production of CaSO_4 . Increases in temperature cause a shift in the sulphur distribution towards the outer edge of the particle due to the faster kinetics of oxidation of SO_2 and hence a more rapid plugging of the pores by the CaSO_4 product.

The effect of limestone particle size is illustrated on Fig. 3 for different limestone types designated as A, H, O and I (Munzner and Bonn, 1980). For certain fluidizing velocity, grain sizes below 0.2 mm are elutriable sorbents whereas those above 0.2 mm are the non-elutriable sorbents. For elutriable sorbents, decrease in stone utilization with increase of the size is due to fact that the time for completing the reaction increases with particle size. The very fine particles with diameter 0.001 mm sulphate quickly due to high specific surface area as they pass through the bed. Further increase in particle size results in an increase in the reaction time, and as a result the sulphation is minimum at about 0.06 mm particle size (these particles are still too fine and will elutriate).

The influence of the much increased time as in the case of non-elutriable sorbent particles is quite obvious as sulphur capture is increased for 0.4 mm particles. However further increase in particle size leads to a decrease in limestone utilization as a result of reduction of the specific surface area.

Experimental data (Highley, 1975) indicate that 20% greater SO_2

DEPENDANCE OF SULPHUR CAPTURE ON PARTICLE SIZE
FOR DIFFERENT TYPE OF LIMESTONES— A,O,H and T

FIG. 3 SULPHUR CAPTURE vs PARTICLE SIZE

removal is achieved with particles smaller than 0.15 mm compared to 3 mm particles at a fluidizing velocity of 0.9 m/sec. However for similar tests, a 15% decrease in SO₂ removal was recorded at 2.4 m/sec fluidizing velocity for the smaller particle size compared with the larger one, because of elutriation of the smaller particles at higher fluidizing velocity. If, on the other hand, elutriated particles are reinjected in the combustor an increase of SO₂ removal of up to 62.5% is measured (Highley, 1975 ; National Coal Board, 1971).

In addition to various chemical processes, sorbent particles, upon injection into the FBC combustor, are subjected to physical processes such as attrition and elutriation. Attrition is caused by mechanical shattering and abrasion, by thermal shock, by internal gas pressure and by chemical stresses (calcination, sulphation) (Kearns, 1984). Attrition is highly dependent on origin of the limestone, i.e. location of the quarry and its geological history. The attrition performance can be determined only after tests from pilot scale units are analyzed (Babcock and Wilcox, 1977-1983). Attrition produces finer particles compared with the initial particle size distribution of the limestone, which affects the sulphation mechanism. Smaller particles have increased surface area for the initial sulphation and with low fluidizing velocity yield higher absorption of SO₂. Small sorbent feed material and fine particles created by attrition, however, will be elutriated from the combustor before sulphation can be completed. For better utilization, these particles are reinjected into the combustor at various recycle rates (Becker and Code, 1982). Significant increase of SO₂ removal has been measured when elutriated material is recycled. It is usual practice, for larger scale FBC units, to employ cyclone ash reinjection for improved efficiency of the sulphur retention as well as combustion (DOE, 1979; Bass and Castleman, 1984; Razbin and Friedrich, 1984).

II.4 - Heat Transfer to Inbed Surfaces

Heat transfer to the inbed tube surfaces in the fluidized bed is by direct solid contact, by conduction and convection through the separating gas layer and by thermal radiation. Typical conditions around a horizontal heat exchanger tube submersed in the bed are shown in Fig. 4 (Glicksman, 1984).

II.4.1 - direct solid contact

As the particles touch the heat transfer surface, near the points of actual solid contact (Fig. 5) there is transient conduction heat transfer, which causes the surface and the particle to approach the same temperature rapidly. For a particle size of 1 mm, which is the size typical for large scale fluidized bed (smaller powdery particles will sputter very quickly upon introduction in the bed), the radius of contact, which determines the area of heat transfer, is less than 0.01 mm (Decker and Glicksman, 1981). At a superficial gas velocity equal to $1.5 U_{mf}$ particles tend to oscillate, intermittently contacting the surface and then moving slightly away. Measurements of the time averaged conduction Nusselt number ($h D_p / k$) indicate decreases of 50% compared to the value found when the particle continuously remains in contact with the surface (the upper limit of the conduction Nusselt number is about 12 when particle is in continuous contact with the surface) (Glicksman, 1984).

II.4.2 - convective heat transfer

The value of Reynolds number ($U_g D_p / \mu$) for larger bed particles is larger because of particle size and the higher value of U_{mf} - the minimum fluidizing velocity. Contribution of the overall convective heat transfer coefficient from the particles to the wall (which includes the effect of convection from the particle to the gas and from the gas to the wall) is due to eddies in the larger voids between the particles near the surface. Correlation

FIG. 5 TEMPERATURE CHANGE of PARTICLES
at TUBE SURFACE with TIME

for convection heat transfer is given as (Baskakov, 1972) :

$$(Nu)_{conv} = h_c \bar{D}_p / k_g$$

$$(Nu)_{conv} = 0.009 (Ar)^{1/2} (Pr)^{1/3} \quad \text{for } Re \leq 2000$$

while for higher Reynolds numbers the correlation is

$$(Nu)_{conv} = 0.18 (Re)^{0.8} (Pr)^{1/3} \quad \text{for } Re > 2000$$

11.4.3 - radiation heat transfer

For a large particle fluidized bed with material having a $D_p > 1$ mm those particles adjacent to the heat transfer tube are approximately at average bed temperature; T_b , and radiation acts independently of conduction and convection i.e. the presence of radiation does not influence the particle temperature and thereby the conduction heat transfer to the surface. Heat transfer can be assumed to occur between two isothermal parallel planes at two different temperatures and in terms of a linearized heat transfer coefficient h_r , (Clicksman, 1984) :

$$(Nu)_{rad} = \frac{h_r k_g}{\bar{D}_p} = \frac{K_g}{\bar{D}_p} \left[\frac{(\sigma T_b^4 - \sigma T_w^4)}{(\frac{1}{\epsilon_b} + \frac{1}{\epsilon_w} - 1)(T_b - T_w)} \right]$$

The total heat transfer coefficient from the particles to the surface is computed by combining conduction, convection and radiation components for $T = T_b - T_w$,

$$(Nu)_{surf.} = (Nu)_{cond.} + (Nu)_{conv.} + (Nu)_{rad.}$$

assuming no interaction between the mechanisms. In reality interaction does occur, which explains why it is so difficult to predict the heat transfer coefficients in FBC units (Glicksman, 1984).

Actual processes in the fluidized bed combustor are more complex than the treatment of the theory, and the practical designer is faced with making various assumptions when sizing the combustor. Numerous correlations and models for the hydrodynamics, the combustion, the sulphation and heat transfer were developed or are being developed and none has been able or can be used to predict all phenomena occurring in the fluidized bed. As a result extensive experimental work on pilot scale as well as on large scale demonstration units is contributing to far better understanding the FBC processes.

The present test program conducted at EMR/CANMET contributes to overall research efforts by adding new test data obtained from firing of high sulphur coal with different limestone sizes at different fluidizing velocities and two recycle regimes.

III. TEST PROGRAM and PROCEDURE

III.1 - Unit Description

The major components of CCRL's pilot scale combustor are shown in Fig. 6. It consists of a combustor and freeboard assembly, systems for feeding the fuel and the sorbent, a multi-clone cyclone for fly ash capture, recycle ash system, extensive instrumentation for flue gas analysis and data logging equipment.

The combustor stands about 4.8 m high with external dimensions of 0.94 x 0.94 m. Internal cross section dimensions are 0.38 x 0.41 m, giving an area of 0.155 m². The combustor, lined with firebricks and refractory, is instrumented with thermocouples and pressure taps. The bottom part of the unit has a cooled water jacket. In addition, there are inserts on two opposite sides of the bed, allowing water-cooled tubes to pass through the bed volume for temperature control. There is facility for up to 48 tubes; however, in this test program up to 20 tubes were used to maintain the temperature (Fig. 7). To ensure identical hydrodynamic conditions for all the tests, all 20 tubes were always inserted in the bed and depending on the heating load, some were cooled to maintain 850 C bed temperature.

The air distributor consists of a 9.5 mm thick plate fitted with 100 nozzles (distributor caps) to provide even distribution of the fluidizing air. The caps are made from 32x13 mm diameter stainless steel bolts and are arranged in a 38x35 mm rectangular pitch. All bolts are drilled with a 6-mm hole through their centre and with four 3-mm holes below the bolt head (Fig. 8). This layout prevents "weeping" (penetration of bed material back into the windbox), forces air to egress horizontally and provides good distribution of the combustion air. A 20-mm gap between the distributor plate and the air jets allows the plate to be covered with layer of material thus preventing plate

FIG. 6 SCHEMATIC of the MAJOR COMPONENTS of AFBC

FIG. 7 IN-BED COOLING TUBES
LAYOUT and DETAIL

FIG. 8 DISTRIBUTOR PLATE NOZZLES
and NOZZLE DETAIL

overheating.

The feed system for the coal consists of a coal hopper and double screw feeding arrangement. Each screw has a variable speed drive for feed rate control. Material from the first feeder drops via flexible hose to the second water-cooled feeder which delivers the coal into the bed (over-bed feeding was not used). The feed point is 144 mm above the distributor plate. The coal hopper sits on an electronic weigh scale and the feed rates are calculated from the change of weight with time. The hopper weight is logged during the test.

The limestone feed system has a variable speed drive for the screw feeder which brings the limestone to the drop pipe. The limestone is mixed with the coal before introduction in the bed.

The multicyclone is connected to the combustor free-board with flexible steel duct. Cyclone products are either collected in a drum for non-recycle tests or injected pneumatically back into the combustor via two pipes. After the cyclone, the dust loading is measured in the flue gas duct to the stack.

The instrumentation consists of NDIR (non-destructive infra-red) recorders for continuous monitoring. Measured and recorded are O_2 , CO_2 , CO , NO_x and SO_2 concentrations. Temperature at various locations in the combustor as well as the cooling circuits are measured and recorded. Logging is via electronic data-logger and is done every 2 or 5 minutes.

Dust loading is measured by a separate system using a vacuum pump to provide an isokinetic sample removal from the duct after the cyclone. Fly ash samples are captured on filter paper and are weighed.

Details of the instrumentation are as follow:

EQUIPMENT / MANUFACTURER	OPERATION	RANGES USED	SENSITIVITY	ACCURACY / REMARKS
SULPHUR DIOXIDE BECKMAN	INFRA-RED	3 RANGES 0 - 10000 ppm	90% FULL SCALE ADJ. .5 to 26 sec	1% of full scale, interference from components in gas, high maintenance
HORIBA	INFRA-RED	3 RANGES 0 - 7500 ppm	90% FULL SCALE ADJ. .5 to 5 sec	0.5% of full scale, interference from components in gas, high maintenance
Western Research	ULTRA-VIOLET	0 - 2000 ppm 0 - 10000 ppm	95% FULL SCALE ADJ. 1 to 3 sec	0.1% of full scale, low maintenance
OXYGEN ANALYZER BECKMAN	PARAMAGNETIC	0 - 25%	90% FULL SCALE ADJ. 5 to 25 sec	1% of full scale, low maintenance
DYNATRON	Zirconia Oxide Cell	0 - 20.9%	90% FULL SCALE ADJ. 5 sec	0.5% of full scale, high maintenance
LEEDS & NORTHROP	Thermo Magnetic Magnetic-Induced Flow	0 - 25%	100% of SCALE ADJ. 1 min.	0.5% of full scale, low maintenance
NITRIC OXIDES Thermo Electric	Chemiluminescence	0 - 10000 ppm in 8 ranges	90% of SCALE ADJ. 1.5 sec	1% of full scale, low maintenance

EQUIPMENT / MANUFACTURER	OPERATION	RANGES USED	SENSITIVITY	ACCURACY / REMARKS
CARBON MONOXIDE BECKMAN	INFRA-RED	3 RANGES 0 - 5 %	90% FULL SCALE ADJ. .5 to 26 sec	1% of full scale, good repeatability, high maintenance
HORIBA	INFRA-RED	2 RANGES 0 - 5 %	90% FULL SCALE ADJ. .5 to 5 sec	0.5% of full scale good repeatability, low maintenance
CARBON DIOXIDE BECKMAN	INFRA-RED	0 - 20 %	90% of SCALE SEL. .5 to 26sec	1% of full scale, good repeatability, high maintenance
HORIBA	INFRA-RED	0 - 20 %	90% of SCALE SEL. .5 to 5sec	0.5% of full scale good repeatability, low maintenance
DATA LOGGER DIGISTRIP III	Analog to Digital Printer, Alarms Interface, Mat Pack. 48 Channels	T/C- Full Range 0 to 65mV to 6.5V	0.5 mV	good accuracy, versatility, small printer, user friendly
KAYE				
RAMP	Analog to Digital Printer, Alarms Interface, Mat Pack. 128 Channels	T/C- Full Range 0 to 40mV to 20V	1.0 mV	good accuracy, limited versatility, non-portable

TABLE 7 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
CA/S MATRIX

TEST No.	DC20	DC21	DC22	DC23	DC24
LIMESTONE SIZE mm	6.3-0	<2:38-0.84>		<6.3-0.84>	
COAL kg/hr	35.6	38.9	37.3	36.2	38.3
LIMESTONE kg/hr	8.1	19.5	12.9	18.5	12.0
Ca/S ratio	2.02	4.06	3.30	4.10	2.10
BED TEMP C	851	850	849	850	847
FLUIDIZING VEL. m/s	<----- 2.1----->				
RECYCLE	YES	NO	YES	NO	YES
O ₂ %	3.6	3.4	3.7	3.6	3.5
CO ₂ %	13.0	15.4	13.8	14.4	13.5
SO ₂ ppm	599	591	582	650	660
CO ppm	1670	842	1530	1088	1328
NO ppm	419	404	335	359	412
CARBON CARRY- OVER %	0.6	5.5	1.2	1.8	1.1
SO ₂ RE- DUCTION %	76.8	79.6	75.8	75.9	82.2

FIG. 9 DEVCO COAL SIEVE ANALYSIS

% CUMULATIVE OVERSIZE vs MESH or MICRONS

STREAM:DEVCO COAL TEST:ALL TESTS (RANGE OF DATA) DATE:1982

FIG.10 LIMESTONE SIEVE ANALYSIS

% CUMULATIVE OVERSIZE vs MESH or MICRONS

STREAM:HAVELOCK LIMEST. TEST:ALL TESTS(RANGE OF DATA) DATE:1982

(. boilers were designed for double screened limestone).

For all tests a starter bed material of "brown sand" was used which is an inert material with respect to sulphur capture. This material had a mean particle size of 1 mm, a particle density of 2580 kg/cub.meter and a bulk density of 1570 kg/cub.meter. A fresh charge of 110 kg of sand was used for each experiment. No attempt was made to achieve a limestone bed i.e. bed inventory with sulphated limestone only. It has been suggested (Becker and Code, 1982) that three bed turnovers would be required, or 12 to 32 hours of operation depending on the feed rate of limestone, to ensure that over 95% of the bed material was sulphated limestone products. Instead, the starting sand bed was brought up in temperature using a charge of charcoal and the coal and limestone feed rates were then established. After bed temperature, feed rates and SO₂ concentration in the flue gas had stabilized, data collected over the next 3 to 6 hour were considered as steady-state data. This allowed testing to be completed in one working day. Only steady-state data were used in the calculations. To verify the above steady-state approach and to study the effect of prolonged operation, two 24-hour tests were also performed. They demonstrated combustion efficiencies and sulphur captures similar to those from the shorter duration runs thus indicating that shorter runs had achieved an effective equilibrium, and allowed usage of the results with confidence.

III.3 - Test Matrix

The test matrix was divided into five sections with common operating conditions for all tests as follows:

- bed temperature at 850 deg C - maintained as nearly as possible using different numbers of cooling tubes
- bed height between 610 and 710 mm (24 to 28 inches) - maintained by removal of material from the bottom of the bed
- excess air - maintained at about 20% or 3.6% O₂ in the flue gas
- test duration of 3 to 6 hours after establishing steady state

The first section of the test matrix, Table 3, consists of tests to establish baseline conditions. The coal was burned in a sand bed without limestone addition at three fluidizing velocities and with or without cyclone ash recycle. Tests were numbered BDC1 to BDC5. The results from one additional test are not reported because analyzer malfunction, not detected at the time, rendered the data unreliable.

The second series of tests - Tables 4, 5 and 6 - form the BASIC MATRIX. The tests were labelled DC1 through DC18 and were intended to evaluate the effect of limestone size consist on sulphur dioxide capture. The coal was burned in the presence of three different size consists of limestone, at three different fluidizing velocities and with or without recycle of the cyclone products. Ca/S ratio was targeted at 3:1. However due to variation of S content in the coal the Ca/S ratio varied considerably. Test DC13 (6.3 mm x 0.84 mm limestone, fluidizing velocity - 3.0 m/sec, without recycle) was not performed.

TABLE 3 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
BASELINE TESTS

TEST No.	BDC1	BDC2	BDC3	BDC4	BDC5
LIMESTONE SIZE mm			N/A		
COAL kg/hr	58.7	57.4	43.3	40.5	26.2
LIMESTONE kg/hr			N/A		
Ca/S ratio			N/A		
BED TEMP C	860	860	855	858	853
FLUIDIZING VEL. m/s	3.0	3.0	2.1	2.1	1.2
RECYCLE	NO	YES	NO	YES	NO
O ₂ %	4.3	4.2	3.5	3.5	3.3
CO ₂ %	14.4	14.1	14.3	13.2	14.7
SO ₂ ppm	4408	4450	4569	3816	5081
CO ppm	1600	1300	1580	1631	777
NO ppm	475	468	416	439	506
CARBON CARRY- OVER %	9.4	—	9.9	—	7.4
SO ₂ RE- DUCTION %	12.1	9.1	13.4	8.3	9.0

TABLE 4.— OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
BASIC MATRIX—1

TEST No.	DC1	DC2	DC3	DC4	DC5	DC6
LIMESTONE SIZE mm	<-----6.3-0----->					
COAL kg/hr	47.5	49.2	37.5	36.6	23.2	21.9
LIMESTONE kg/hr	24.0	22.2	17.8	15.9	12.4	11.5
Ca/S ratio	4.49	4.04	4.11	3.77	5.71	4.86
BED TEMP C	852	856	849	850	849	847
FLUIDIZING VEL. m/s	3.0	3.0	2.1	2.1	1.2	1.2
RECYCLE	NO	YES	NO	YES	NO	YES
O ₂ %	3.7	3.5	3.4	3.3	3.3	3.6
CO ₂ %	12.7	12.6	13.4	14.4	14.4	16.0
SO ₂ ppm	736	315	650	197	534	141
CO ppm	1160	411	1623	1277	1007	1397
NO ppm	314	318	349	338	288	268
CARBON CARRY- OVER %	6.8	1.6	5.9	1.3	3.4	0.3
SO ₂ RE- DUCTION %	71.4	87.6	76.2	92.8	75.8	94.2

TABLE 5 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
BASIC MATRIX—2

TEST No.	DC7	DC8	DC9	DC10	DC11	DC12
LIMESTONE SIZE mm	<----- 2.38-0.84 ----->					
COAL kg/hr	58.2	52.2	39.3	40.2	24.4	22.9
LIMESTONE kg/hr	24.3	24.1	20.0	18.6	11.8	12.3
Ca/S ratio	2.57	3.15	3.29	2.84	3.04	3.33
BED TEMP C	852	854	850	851	854	860
FLUIDIZING VEL. m/s	3.0	3.0	2.1	2.1	1.2	1.2
RECYCLE	NO	YES	NO	YES	NO	YES
O ₂ %	3.3	3.5	3.3	3.3	3.6	3.5
CO ₂ %	14.5	15.0	14.2	15.2	13.4	15.2
SO ₂ ppm	1478	952	992	819	1859	782
CO ppm	1081	1075	672	1199	367	247
NO ppm	368	319	493	339	622	543
CARBON CARRY— OVER %	7.4	1.0	7.2	1.1	5.7	0.5
SO ₂ RE— DUCTION %	62.9	73.0	73.2	78.4	51.1	79.3

TABLE 6 - OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
BASIC MATRIX-3

TEST No.	DC14	DC15	DC16	DC17	DC18
LIMESTONE SIZE mm	<----- 6.3-0.84 ----->				
COAL kg/hr	48.1	39.2	36.0	23.2	22.1
LIMESTONE kg/hr	24.3	17.7	16.5	11.1	9.9
Ca/S ratio	4.43	3.42	3.90	4.64	3.77
BED TEMP C	849	852	849	850	849
FLUIDIZING VEL. m/s	3.0	2.1	2.1	1.2	1.2
RECYCLE	YES	NO	YES	NO	YES
O2 %	3.0	3.7	3.4	3.0	3.5
CO2 %	13.0	13.1	14.1	15.1	13.6
SO2 ppm	251	1235	309	554	283
CO ppm	504	910	1430	573	1098
NO ppm	366	332	291	395	284
CARBON CARRY- OVER %	3.8	3.6	0.9	0.6	0.4
SO2 RE- DUCTION %	90.9	58.6	88.2	76.9	89.3

In the third series of tests - Table 7 - the objective was to establish the feed rate of different limestone size consists required to meet the Environment Canada emission guideline of 705 nanograms SO₂ per J of heat input. Tests DC20 through DC24 were conducted at a constant coal feed rate and constant fluidizing velocity, with and without cyclone ash recycle.

In the forth section - Table 8 - two runs of 24 hours each (EDC1 and EDC2) were carried out to compare with shorter duration tests and also to determine whether build-up of oversize material in the combustor will present problems with fluidization in the bed. Two size consists of limestone were used - 6.3 mm x 0 and 2.38 mm x 0.84 mm, recycle was employed, and fluidizing velocity was varied from 2.1 to 1.2 to 2.1 m/sec to check for loss of fluidization in the bed or defluidization.

The fifth series of tests - Table 9 - was aimed at determining the effect of Na₂CO₃ on the sulphur capture of limestone. Four tests (DC25 through DC28) were run using one limestone size - 2.38 x 0.84 mm, with and without recycle. Two aqueous solutions of Na₂CO₃ were prepared - one with 0.1 mole % of Na₂CO₃ and the second with 4.0 mole % of Na₂CO₃ - and were sprayed over the limestone. The mixture was allowed to dry and then was fed to the combustor. Feed rate of coal and the fluidizing velocity were constant, while the limestone feed was varied to maintain SO₂ emissions at or below a target of 705 nanograms SO₂ per J of heat input.

TABLE 7 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
CA/S MATRIX

TEST No.	DC20	DC21	DC22	DC23	DC24
LIMESTONE SIZE mm	6.3-0	<2:38-0.84>		<6.3-0.84>	
COAL kg/hr	35.6	38.9	37.3	36.2	38.3
LIMESTONE kg/hr	8.1	19.5	12.9	18.5	12.0
Ca/S ratio	2.02	4.06	3.30	4.10	2.10
BED TEMP C	851	850	849	850	847
FLUIDIZING VEL. m/s	<----- 2.1----->				
RECYCLE	YES	NO	YES	NO	YES
O2 %	3.6	3.4	3.7	3.6	3.5
CO2 %	13.0	15.4	13.8	14.4	13.5
SO2 ppm	599	591	582	650	660
CO ppm	1670	842	1530	1088	1328
NO ppm	419	404	335	359	412
CARBON CARRY- OVER %	0.6	5.5	1.2	1.8	1.1
SO2 RE- DUCTION %	76.8	79.6	75.8	75.9	82.2

TABLE 8 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
24hr TEST MATRIX

TEST No.	EDC1	EDC1	EDC1	EDC2	EDC2
LIMESTONE SIZE mm	<-----6.3-0----->< 6.3-0.84 >				
COAL kg/hr	35.3	21.1	28.7	33.2	21.9
LIMESTONE kg/hr	11.3	7.4	10.4	11.7	8.2
Ca/S ratio	2.03	2.22	2.29	2.23	2.37
BED TEMP C	840	843	847	842	850
FLUIDIZING VEL. m/s	2.1	1.2	2.1	2.1	1.2
RECYCLE	<-----YES----->				
O2 %	3.3	3.4	3.3	3.5	3.6
CO2 %	15.3	15.0	13.7	14.5	15.2
SO2 ppm	122	147	166	634	620
CO ppm	1327	469	310	1097	556
NO ppm	255	234	296	361	464
CARBON CARRY- OVER %	1.4	—	—	2.4	1.4
SO2 RE- DUCTION %	93.2	92.2	92.0	74.1	68.6

TABLE 9 — OPERATING CONDITIONS for DEVCO PRINCE COAL
and
HAVELOCK LIMESTONE
Na₂CO₃ MATRIX

TEST No.	DC25	DC26	DC27	DC28
Na ₂ CO ₃ MOL %	<---0.1--->		<---4.0--->	
COAL kg/hr	36.8	31.6	35.0	32.6
LIMESTONE kg/hr	13.9	8.0	8.3	7.2
Ca/S ratio	3.43	2.20	2.38	2.14
BED TEMP °C	849	846	848	850
FLUIDIZING VEL. m/s	<-----2.1----->			
RECYCLE	NO	YES	NO	YES
O ₂ %	3.4	3.3	3.4	3.3
CO ₂ %	12.3	12.6	12.0	12.6
SO ₂ ppm	590	664	630	687
CO ppm	1342	1655	2008	2814
NO ppm	397	372	266	213
CARBON CARRY- OVER %	5.8	1.4	9.4	0.9
SO ₂ RE- DUCTION %	80.0	75.2	75.0	72.3

For the range of test data, the following equations correlating sulphur retention and Ca/S ratio were obtained - Fig. 14 :

$$\% \text{ S retention} = 100(1 - \exp(-(0.057 \text{ Ca/S} + 0.330)\text{Ca/S})). \text{ w/ recycle}$$

and

$$\% \text{ S retention} = 100(1 - \exp((0.033 \text{ Ca/S} - 0.443)\text{Ca/S})) \text{ w/no recycle}$$

These equations are similar to those proposed by others (Wright, 1972; Becker and Code, 1982),

$$\% \text{ S retention} = 100(1 - \exp(M \text{ Ca/S}))$$

with the exception that both factors (see Appendix A12)

$$M = -(0.057 \text{ Ca/S} + 0.330)$$

and

$$M = (0.033 \text{ Ca/S} - 0.443)$$

are not constants and not a function of the fluidizing velocity or the bed level . The factor M was plotted vs Ca/S ratio and regression analysis performed with results attached in the Appendix A12. The results indicated that for the tests with no recycle the line has a positive slope while for the tests with recycle the line has a negative slope.

The sulphur retention for tests with and without recycle was plotted against the fluidizing velocity for two limestone size consists, as indicated on Figs. 15 and 16. Little influence of the fluidizing velocity was observed. Cyclone ash recycle has a significant influence as indicated previously. Comparing both graphs it will appear that tests with recycle of 2.38 mm x 0.84 mm limestone give identical results to tests with no recycle of

variance, deviation, preliminary analysis of variance, table of analysis of variance, regression coefficients and 95% confidence intervals is attached in Appendices A4 to A9, after each set of plotted parameters for O₂, SO₂, CO₂, CO, NO_x and the bed temperature. In addition a typical example of the plots and the analysis is attached in Chapter VI.

A summary of all plotted parameters is presented in Tables 3 to 9. Each table shows the mean value of every parameter calculated. The last two parameters in every table are carbon carryover - % and sulphur dioxide reduction - %. Carbon carryover was calculated from the dust loading measurements performed during the steady-state condition for every test. The measured carbon content of the fly ash was related to the total carbon input of the fuel. No unburned carbon was measured in the bed material samples.

Sulphur dioxide reduction was calculated from the measured value of the SO₂ in the flue gas and from the theoretical value of the SO₂ for the percent excess air during the test shown in the Appendix A1.

Samples of bed material leaving the combustor and of cyclone ash leaving the cyclone separator were collected and sieve analyses performed. In the Appendices A10 and A11, graphs of all the sieved samples of bed material and cyclone ash are attached. The graphs were plotted using the computer code, listing of which is also attached with the Appendices A10 and A11. Summary plots - range of data - of bed material and cyclone ash sieve analysis are shown on Fig. 11 and Fig. 12.

Sulphur Retention

Devco Prince coal for the tests was received in three batches. The sulphur content varied from 3 to 6% as indicated from the

FIG.11 BED MATERIAL SIEVE ANALYSIS

% CUMULATIVE OVERSIZE vs MESH or MICRONS

STREAM:BED MATERIAL TEST:ALL TESTS (RANGE OF DATA) DATE:1982

FIG.12 CYCLONE ASH SIEVE ANALYSIS

% CUMULATIVE OVERSIZE vs MESH or MICRONS

STREAM:CYCLONE ASH TEST:ALL TESTS (RANGE OF DATA) DATE:1982

tables in the combustion calculation plots. For the baseline tests observed average SO₂ concentration was 4630 ppm. Calculated theoretical SO₂ concentration would be about 5200 ppm for 4.93% sulphur in the coal, which indicates that ash constituents of the coal captured about 11% of the total sulphur dioxide released during combustion.

During the tests with limestone addition, the Ca/S ratio varied between 2.03 and 4.86 except for one test where it was 5.7. It was observed that for all three different limestone size consists, the sulphur dioxide capture was significantly higher in the tests with cyclone ash recycle, compared to the tests without cyclone ash recycle. This is illustrated on Fig. 15, which is for tests DC3, DC20, DC21, DC22, DC23 and DC24, where Ca/S ratio was adjusted to meet the requirement of 705 nanograms of SO₂ / J of heat input, which is approximately equal to 700 ppm of SO₂ in the flue gas for the percent excess air used. . .

For the tests with recycle, the Ca/S ratio for limestone size consists of 6.3 mm x 0 and 6.3 mm x 0.84 mm is near 2.0 and for double screened limestone of 2.38 mm x 0.84 mm, the Ca/S ratio is 3.30. For tests without recycle the Ca/S ratio for all limestone size consists is over 4.0. The 6.3 mm x 0 limestone gives better sulphur capture than the other two limestones; this is due to the presence of large proportion of fines and a greater surface area for the sulphation reaction. The other limestone size - 6.3 mm x 0.84 mm - performed better than 2.38 mm x 0.84 mm, due to the fact that during the sieving of the 6.3 mm x 0 (to obtain 6.3 mm x 0.84 mm) some of the fine dust particles adhered to the larger particles, thus giving an increased surface area. Sulphur dioxide capture ranged from 51.1 % to 76.9 % and was achieved with a Ca/S ratios of 3.0 to 4.1 in the tests without recycle. In the tests with recycle, Ca/S ratios of 3.2 to 4.9 resulted in sulphur capture ranging from 73.0 % to 94.2 %. All the results are in Tables 4 to 6 i.e. part of the BASIC MATRIX series of tests.

FIG. 13 SO₂ RETENTION vs CA/S RATIO

-45-

In the CA/S MATRIX shown in Table 7, where limestone feed rate was varied to meet the SO₂ guidelines, sulphur dioxide capture is relatively constant, ranging from 75.8 % to 82.2 %, while the Ca/S ratio varies by a factor of two.

In the Na₂CO₃ MATRIX tests, shown in Table 9, the limestone/Na₂CO₃ flow rate was adjusted to meet the SO₂ guidelines. In these tests, sulphur dioxide capture varied from 72.3 % to 80.0 % and the Ca/S ratios were from 2.20 to 3.43. It was observed that a lower concentration of Na₂CO₃ gives somewhat better results in terms of sulphur capture than a higher concentration. The reason for this is difficult to explain. From bench scale tests it has been reported by ANL (Smith et.al. 1981) that an optimum concentration of Na₂CO₃ to promote the sulphation reaction exists and that higher concentration can actually slow down the sulphation reaction. One possible explanation given in the ANL report, is the catalytic effect of the Na₂CO₃ on the sulphation reaction. The optimum concentration is expected to vary from limestone to limestone and is best determined experimentally. During the Devco Prince trials only two Na₂CO₃ concentrations were tested. The results indicate that 0.1 mole % Na₂CO₃ is closer to the optimum concentration (further testing was not performed since large-scale application of the technique is unlikely due to possibility of corrosion from the Na₂CO₃ salt (Combustion, 1981) in large FBC boilers).

In the 24 hr TESTS MATRIX shown in Table 8 similar results were obtained to those previously discussed for the BASIC MATRIX i.e. 6.3 mm x 0 limestone performed better in terms of sulphur capture than double-screened 2.38 mm x 0.84 mm limestone. For identical Ca/S ratios, SO₂ reduction is 20 % better for the cases with recycle. This is a further indication that recycle should always be included in the design of large scale FBC combustors.

For the range of test data, the following equations correlating sulphur retention and Ca/S ratio were obtained - Fig. 14 :

$$\% \text{ S retention} = 100(1 - \exp(-(0.057 \text{ Ca/S} + 0.330)\text{Ca/S})). \text{ w/ recycle}$$

and

$$\% \text{ S retention} = 100(1 - \exp((0.033 \text{ Ca/S} - 0.443)\text{Ca/S})) \text{ w/no recycle}$$

These equations are similar to those proposed by others (Wright, 1972; Becker and Code, 1982),

$$\% \text{ S retention} = 100(1 - \exp(M \text{ Ca/S}))$$

with the exception that both factors. (see Appendix A12)

$$M = -(0.057 \text{ Ca/S} + 0.330)$$

and

$$M = (0.033 \text{ Ca/S} - 0.443)$$

are not constants and not a function of the fluidizing velocity or the bed level . The factor M was plotted vs Ca/S ratio and regression analysis performed with results attached in the Appendix A12. The results indicated that for the tests with no recycle the line has a positive slope while for the tests with recycle the line has a negative slope.

The sulphur retention for tests with and without recycle was plotted against the fluidizing velocity for two limestone size consists, as indicated on Figs. 15 and 16. Little influence of the fluidizing velocity was observed. Cyclone ash recycle has a significant influence as indicated previously. Comparing both graphs it will appear that tests with recycle of 2.38 mm x 0.84 mm limestone give identical results to tests with no recycle of

SULPHUR RETENTION vs Ca/S RATIO WITH DIFFERENT LIMESTONE SIZES

FIG. 14

FIG. 15
SO₂ RETENTION vs FLUIDIZING VELOCITY
PILOT SCALE DEVCO TRIALS - 1982

FIG. 16
SO₂ RETENTION vs FLUIDIZING VELOCITY
PILOT SCALE DEVCO TRIALS - 1982

6.3 mm x 0 limestone size consist.

Carbon Combustion Efficiency

Carbon loss under various test conditions is given in Tables 3 to 9. With recycle tests, except for two tests - DC14 and one 24 hour test with carbon loss of 3.8 % and 2.4% - the values ranged from 0.3 to 1.9 %. For the tests without recycle the values ranged from 1.8 % to 7.4 %, except for two tests - DC17 with carbon loss of 0.6 % and DC27 with carbon loss of 9.4 %. From these results, it can be concluded that recycle of cyclone ash material improves the carbon combustion efficiency. As indicated earlier, unburned carbon was found in the fly ash only.

In the tests with and without cyclone ash recycle, the carbon combustion efficiency decreased slightly as the fluidizing velocity increased, indicating increased carryover from the bed. Different limestone size consists did not have any significant effect on the carbon combustion efficiency. There is considerable scatter in the data and no attempt was made to obtain a correlation.

Emissions of NO_x

The NO_x concentrations in the flue gas varied from 213 to 622 ppm as given in Tables 3 to 9 but for most of the tests the values were below 480 ppm. The low NO_x values (compare to emissions from pulverized coal firing, which are in the order of a few thousand ppm's (.Combustion, 1981)) confirm one of the advantages of an FBC. Due to lower temperature in the combustor only fuel nitrogen

is converted to NOx and nitrogen from the air leaves unbound.

In tests with recycle, NOx concentrations were generally lower than in the tests without recycle. There is no apparent correlation between NOx and fluidizing velocity or limestone size consists.

Emissions of CO

CO concentration in the flue gas varied widely - from 247 ppm to 1670 ppm in the tests DC1 to DC24 and from 1342 ppm to 2814 ppm in the tests DC25 to DC28. The data reveal no correlation between CO concentration and limestone size consists, fluidizing velocity or cyclone ash recycle (CO emissions are function of the combustor design, i.e. location of overfired air (if any); design of the distributor plate for uniform air distribution, location of the feeding points for the fuel and temperature in the free board of the combustor).

Defluidization during 24 - hour tests

Two 24-hour tests, performed on July 5 and 19 1982, had as a primary objective to study the effects of prolonged operation on bed inventory and hence fluidization. These tests were performed in an attempt to simulate operation at Summerside, where the possibility of accumulation of larger particles at the bottom of the combustor can create serious problems.

On July 5/82, in the test with 6.3 mm x 0 limestone, after 12 hours of operation the fluidizing velocity was reduced from 2.1 m/sec to 1.2 m/sec. In about 90 minutes the temperatures at two bottom elevations in the combustor - at 50 mm (T2) and 125 mm (T7) above the distributor plate nozzles - started to drop, (see Appendix A9) indicating onset of defluidization. After approximately 5.5 hours at lower velocity a similar drop in temperature was observed at the 125 mm level. The fluidizing velocity was then increased back to 2.1 m/sec, and the temperature in the lower levels rose back to bed temperature, indicating that good fluidization had been re-established. Plots of temperature variation for this 24 hours test are attached in the Appendix A9.

In the other 24-hour test conducted on July 19/82 with 2.38 mm x 0.84 mm limestone, again the fluidizing velocity was reduced to 1.2 m/sec after 12 hours of operation at 2.1 m/sec. It was observed that defluidization at the 50 mm level occurred after approximately 8 hours operation at lower fluidizing velocity. At the 125 mm level the temperature drop was only about 20 C. Fluidizing velocity was increased to 1.5 m/sec and shortly after the temperatures were restored to bed temperature. Plots of temperature variation for the second 24 hour test are attached in the Appendix A9 and also in Chapter VI.

These observations indicate that at low velocity - 1.2 m/sec - defluidization can be a problem but less so with 2.38 mm x 0.84 mm limestone. A small increase in the fluidizing velocity can restore fluidization at the bottom levels of the combustor. This information is useful for design and operation of large scale fluidized bed boilers where defluidization can occur at low load operation.

V. CONCLUSIONS

Devco Prince coal containing up to 6 % sulphur can be successfully burnt in an atmospheric fluidized bed combustor. During the pilot scale tests combustion efficiencies ranged from 96.2 % to 99.7 % when cyclone ash material was recycled and from 92.6 % to 98.2 % without cyclone ash recycle. Limestone particle size consist has little effect on the combustion efficiency.

In the tests without cyclone recycle, sulphur capture of 51.1 % to 76.9 % was achieved with Ca/S ratios of 2.57 to 5.71. Significant improvement in the sulphur capture was achieved when recycle of cyclone ash was employed. Sulphur capture of 73 % to 92.8 % was measured with a Ca/S ratio of 3.15 to 4.86.

Equations correlating sulphur retention as a function of Ca/S mole ratio for tests with and without recycle were obtained as follow:

$$\% \text{ S retention} = 100(1 - \exp(-(0.057 \text{ Ca/S} + 0.330)\text{Ca/S})) \text{ w/ recycle}$$

and

$$\% \text{ S retention} = 100(1 - \exp((0.033 \text{ Ca/S} - 0.443)\text{Ca/S})) \text{ w/no recycle}$$

In tests with cyclone ash recycle, SO₂ reduction was up to 20% higher than for tests without recycle at identical Ca/S ratios.

To meet Environment Canada emission guidelines of 705 nanograms SO₂ per J of heat input, the Ca/S ratio can be reduced to 2.02 when 6.3 mm x 0 limestone is used with cyclone ash recycle. It is concluded that this limestone gives the greatest sulphur capture.

Comparing recycle with non-recycle tests, reduction of limestone

consumption by half can be achieved. This can result in dramatic reduction in limestone cost as well as reduction in ash disposal cost. In industrial and utility fluidized bed boilers, recycle should always be used.

Addition of Na_2CO_3 to the limestone improves slightly the sulphation but increased cost with limestone preparation and potential corrosion problems make application of the technique in large scale FBC installations impractical.

Defluidization can occur at lower fluidizing velocities during prolonged operation. It is not, however, viewed as a serious problem because a small increase of fluidizing velocity restores fluidization throughout the bed.

VI. TEST EXAMPLE
of RECORDED DATA
and ANALYSIS

TABLE 10. ANALYTICAL DATA - DEVCO COAL and HAVELOCK LIMESTONE

ANALYTICAL DATA

DEVCO COAL AND HAVELOCK LIMESTONE

	COAL	LIMESTONE
PROXIMATE ANALYSIS, % DRY		
ASH	18.93	N/A
VOLATILES	31.68	N/A
FIXED CARBON	49.39	N/A
ULTIMATE ANALYSIS, % DRY		
CARBON	65.19	N/A
HYDROGEN	4.42	N/A
SULPHUR	4.93	N/A
NITROGEN	1.16	N/A
ASH	18.93	N/A
OXYGEN (BY DIFFERENCE)	5.37	N/A
GROSS CALORIFIC VALUE, MJ/kg	27.1	N/A
EQUILIBRIUM MOISTURE, %	3.16	N/A
MAJOR ELEMENTS, % WT.		
SiO ₂	37.3	2.50
Al ₂ O ₃	23.6	0.49
Fe ₂ O ₃	30.1	0.50
TiO ₂	0.7	0.13
P ₂ O ₅	0.1	0.00
CaO	1.5	52.96
MgO	1.3	0.00
SO ₃	1.5	0.41
Na ₂ O	0.5	0.06
K ₂ O	2.2	0.16
UNDETERMINED / LOF	1.2	42.71

DEVCO COAL COMBUSTION CALCULATIONS

1. STOICHIOMETRIC AIR REQUIRED / DRY COAL

$$C \rightarrow 32/12.01 \times 0.6519 = 1.737$$

$$H \rightarrow 8/1.008 \times 0.0442 = 0.351$$

$$S \rightarrow 32/32.066 \times 0.0493 = 0.0049$$

$$\text{SUMMATION} = 2.137$$

$$\text{LESS OXYGEN IN COAL} = 0.053$$

$$\text{OXYGEN REQUIRED} \rightarrow = 2.084$$

$$\text{ASSOCIATED N}_2 \rightarrow 76.85/23.15 \times 2.084 = 6.920$$

$$\text{AIR REQUIRED / DRY COAL} \rightarrow \text{SUMMATION} = 9.004$$

2. STOICHIOMETRIC PRODUCT OF COMBUSTION by WEIGHT

DRY FLUE GAS / DRY COAL

$$C \rightarrow 1.737 + 0.6519 = 2.3889 - \text{CO}_2$$

$$N \rightarrow 6.920 + 0.0116 = 6.9316 - \text{N}_2$$

$$S \rightarrow 0.049 + 0.0493 = 0.0983 - \text{SO}_2$$

$$\text{DRY PRODUCT - SUMM.} = 9.4188$$

WET PRODUCT - H₂ FROM FUEL ONLY

$$H_2 \rightarrow 0.351 + 0.0442 = 0.3952$$

$$\text{WET PRODUCT - SUMM.} = 9.8140$$

3. EXCESS AIR - 20%, 40%, 60%

$$\text{Additional O}_2 \rightarrow \% \text{ EX. AIR} \times 2.084$$

$$\text{Additional N}_2 \rightarrow \% \text{ EX. AIR} \times 6.920$$

$$\text{Additional WEIGHT} = \text{Add. O}_2 + \text{Add. N}_2$$

TOT. AIR %	Add. WEIGHT	DRY PROD.	WET PROD.
100	0.000	9.4188	9.8140
120	1.8008	11.2196	11.6148
140	3.6016	13.0204	13.4156
160	5.4024	14.8212	15.2164

FIG. 17 TOTAL COMBUSTION AIR - (%) vs
AIR & FLUE GAS, SO₂, O₂, and CO₂

FIG. 18 TOTAL COMBUSTION AIR - (%) vs
 DRY & TOTAL PRODUCTS, O₂, and CO₂

COAL FEED RATE kg/hr 24-hrs. TEST

COAL FEED

COAL FEED RATE kg/hr 24 hrs. TEST

COAL FEED

FIG. 19 COAL FEED RATE (kg/hr) - 24 hr vs TIME x 2 min.

LIME STONE FEED RATE kg/hr 24 hrs. [1951]

LIME STONE FEED RATE kg/hr 24 hrs. [1951]

FIG: 20 LIMESTONE FEED RATE (kg/hr) - 24 hr vs TIME x 2 min.

TEMP 2 24 hr TEST JULY 1982

TEMP 2 24 hr TEST JULY 1982

FIG. 21 TEMP 2 (deg.C) 24 hr TEST vs TIME x 2 min.

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
TEMP 2	629	861.70572	1543.16892	39.28319	4.55877

CORRELATION = -.20987

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	969110.07939512			
X 1	42683.47192220	28.8879191070		(1.677)
	.0440439872			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .04404
STANDARD ERROR OF ESTIMATE = 38.4389697818

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	969110.079395		
REGRESSION	1	42683.471922	42683.471922	28.8879
X 1	1	42683.471922	42683.471922	28.8879
RESIDUAL	627	926426.607473	1477.554398	

Confidence coefficient (e.g., 90, 95, 99) = ?

TABLE 11. REGRESSION ANALYSIS
coefficients and analysis of variance—TEMP 2

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T-VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	875.99649	.875996493271E+03	3.06898	285.44
X 1	-.04537	-.453675234342E-01	.00844	-5.37

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	875.99649	869.96843	882.02455
X 1	-.04537	-.06195	-.02879

Plot regression curve on present graph

TABLE 11a. REGRESSION ANALYSIS
coefficients and analysis of variance—TEMP 2 (cont.)

101 OXYGEN 24 hr TEST JUL 7 1982

101 OXYGEN 24 hr TEST JUL 7 1982

FIG. 22 OXYGEN (%) 24 hr TEST vs TIME x 2 min.

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
OXYGEN	629	3.74338	1.66393	1.28993	34.45449

CORRELATION = .27235

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	1044.94893482			
X 1	77.50903863		50.2337844581	(1.627)
	.0741749535			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .07417
STANDARD ERROR OF ESTIMATE = 1.24216196271

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	1044.948935		
REGRESSION	1	77.509039	77.509039	5
0.2338				
X 1	1	77.509039	77.509039	5
0.2338				
RESIDUAL	627	967.439896	1.542966	

Confidence coefficient (e.g., 90, 95, 99) = ?

TABLE 12. REGRESSION ANALYSIS
coefficients and analysis of variance—OXYGEN

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	3.13490	.313490071188E+01	.09917	31.61
X 1	.00193	.193326495687E-02	.00027	7.09

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	3.13490	2.94010	3.32970
X 1	.00193	.00140	.00247

Plot regression curve on present graph ?

TABLE 12a. REGRESSION ANALYSIS
coefficients and analysis of variance—OXYGEN (cont.)

103 CO2 24 hr TEST JULY 19 62

CO2

103 CO2 24 hr TEST JULY 19 62

FIG. 23 CO2 (%) 24 hr TEST vs TIME x 2 min.

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min.	629	315.00000	13022.50000	114.12094	57.68919
CO2	629	14.62957	5.04795	2.24675	15.35769

CORRELATION = .11465

PRELIMINARY ANALYSIS

SOURCE	SS (ADDITIONAL)	DF	R (CUMULATIVE)
TOTAL (ADJ)	3170.10998410		
X 1	41.67294186	1	0.152079978 (1.627)
	.0131455824		

Degree of regression ($k=1$) = 1

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .01315
STANDARD ERROR OF ESTIMATE = 2.23372620586

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	3170.109984		
REGRESSION	1	41.672942	41.672942	
3.3521				
X 1	1	41.672942	41.672942	
8.3521				
RESIDUAL	627	3128.437042	4.989513	

Confidence coefficient (e.g., 90, 95, 99)

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	F-FORMAT	STANDARD ERROR REG. COEFFICIENT	F-VALUE
CONSTANT	14.18304	.141830384900E+02	1.7334	79.53
X 1	.00142	.141756272142E-02	.00043	1.73

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	14.18304	13.83274	14.53333
X ¹	.00142	.00045	.00238

Plot regression curve on present graph ?

TABLE 13a. REGRESSION ANALYSIS
coefficients and analysis of variance—CO₂ (cont.)

102 CO 24hr TEST JUL 1 1950

102 CO 24hr TEST JUL 1 1950

FIG. 24 CO (%) 24 hr TEST vs TIME x 2-min.

2

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TINEX2 min	629	315.00000	33022.50000	181.72094	57.68919
CO	629	1067.48808	802954.50822	896.07729	83.94260

CORRELATION = -.43686

PRELIMINARY ADV.

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL(ADJ)	504255431.16057200			
X 1	96235439.04814920	147.8839798285		(1.627)
	.1908466089			

Degree of regression - (<= 1) = 2

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .9085
STANDARD ERROR OF ESTIMATE = 806.690516057

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	504255431.160572		
REGRESSION	1	96235439.048149	96235439.048149	147.88
X 1	1	96235439.048149	96235439.048149	147.88
RESIDUAL	627	408019992.112423	650749.588696	

Confidence coefficient (e.g., 90, 95, 99) = 2

TABLE 14. REGRESSION ANALYSIS
coefficients and analysis of variance—CO

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	1746.05592	.174605591729E+04	64.40650	27.11
X 1	-2.15418	-.215418362215E+01	.17714	-12.16

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	1746.05592	1619.54946	1872.56237
X 1	-2.15418	-2.50212	-1.80624

Plot regression curve on present graph ?

TABLE 14a. REGRESSION ANALYSIS
coefficients and analysis of variance—CO (cont.)

216 SO2 24hr TEST JULY 1982

SO2

216 SO2 24hr TEST JULY 1982

SO2

FIG. 25 SO2 (%) 24 hr TEST vs TIME x 2 min.

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.01590	33018.51886	181.70999	57.68280
SO2	629	652.86169	192027.78498	438.20975	67.12138

CORRELATION = -.29633

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	120593448.96661400			
X 1	10589711.83976370	60.3593068468	1	(1.627)
	.0878133259			

Degree of regression (≤ 1) = 2

SELECTED DEGREE OF REGRESSION = 1
R²SQUARED = .08781
STANDARD ERROR OF ESTIMATE = 418.861023278

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	120593448.966614		
REGRESSION	1	10589711.839764	10589711.839764	6
0.3593				
X 1	1	10589711.839764	10589711.839764	6
0.3593				
RESIDUAL	627	110003737.126850	175444.555821	

Confidence coefficient (e.g., 90, 95, 99) = 2

TABLE 15. REGRESSION ANALYSIS
coefficients and analysis of variance-SO2

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	877.98264	.877982643025E+03	33.44481	26.25
X ¹	-.71463	-.714633639319E+00	.09198	-7.77

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	877.98264	812.29075	943.67454
X ¹	-.71463	-.89531	-.53396

Plot regression curve on present graph

TABLE 15a. REGRESSION ANALYSIS
coefficients and analysis of variance—SO₂ (cont.)

105 NO 24 hr TEST JULY 1982

105 NO 24 hr TEST JULY 1982

FIG. 26 NO (%) 24 hr TEST vs TIME x 2 min.

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIME X2 min	629	315.00000	33022.50000	181.72094	57.68919
NO	629	358.65183	19976.88018	141.33959	39.40858

CORRELATION = .17870

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	12545480.75039750			
X 1	400601.33027154	20.6817231684	(1,627)	
	.0319319234			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .03193
STANDARD ERROR OF ESTIMATE = 139.175513782

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	12545480.750397		
REGRESSION	1	400601.330272	400601.330272	20.6817
X 1	1	400601.330272	400601.330272	20.6817
RESIDUAL	627	12144879.420126	19369.823637	

Confidence coefficient (e.g., 90, 95, 99) = ?

TABLE 16. REGRESSION ANALYSIS
coefficients and analysis of variance—NO

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR		T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT		
CONSTANT	314.87120	.314871203913E+03	11.11183		28.34
X 1	.13899	.138986109162E+00	.03056		4.55

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	314.87120	293.04548	336.69692
X 1	.13899	.07896	.19902

Plot regression curve on present graph ?

TABLE 16a. REGRESSION ANALYSIS
coefficients and analysis of variance—NO (cont.)

VII. APPENDICES

APPENDIX A1

COMBUSTION CALCULATION GRAPHS

ANALYTICAL DATA

DEVCO COAL AND HAVELOCK LIMESTONE

	COAL	LIMESTONE
PROXIMATE ANALYSIS, % DRY		
ASH	18.93	N/A
VOLITILES	31.68	N/A
FIXED CARBON	49.39	N/A
ULTIMATE ANALYSIS, % DRY		
CARBON	65.19	N/A
HYDROGEN	4.42	N/A
SULPHUR	4.93	N/A
NITROGEN	1.16	N/A
ASH	18.93	N/A
OXYGEN (BY DIFFERENCE)	5.37	N/A
GROSS CALORIFIC VALUE, MJ/kg	27.1	N/A
EQUILIBRIUM MOISTURE, %	3.16	N/A
MAJOR ELEMENTS, % WT.		
SiO ₂	37.3	2.50
Al ₂ O ₃	23.6	0.49
Fe ₂ O ₃	30.1	0.50
TiO ₂	0.7	0.13
P ₂ O ₅	0.1	0.00
CaO	1.5	52.96
MgO	1.3	0.00
SO ₃	1.5	0.41
Na ₂ O	0.5	0.06
K ₂ O	2.2	0.16
UNDETERMINED / LOF	1.2	42.71

DEVCO COAL COMBUSTION CALCULATIONS

1. STOICHIOMETRIC AIR REQUIRED / DRY COAL

$$C \rightarrow 32/12.01 \times 0.6519 = 1.737$$

$$H \rightarrow 8/1.008 \times 0.0442 = 0.351$$

$$S \rightarrow 32/32.066 \times 0.0493 = 0.0049$$

$$\text{SUMMATION} = 2.137$$

$$\text{LESS OXYGEN IN COAL} = 0.053$$

$$\text{OXYGEN REQUIRED} \rightarrow = 2.084$$

$$\text{ASSOCIATED N}_2 \rightarrow 76.85/23.15 \times 2.084 = 6.920$$

$$\text{AIR REQUIRED / DRY COAL} \rightarrow \text{SUMMATION} = 9.004$$

2. STOICHIOMETRIC PRODUCT OF COMBUSTION by WEIGHT

DRY FLUE GAS / DRY COAL

$$C \rightarrow 1.737 + 0.6519 = 2.3889 \rightarrow \text{CO}_2$$

$$N \rightarrow 6.920 + 0.0116 = 6.9316 \rightarrow \text{N}_2$$

$$S \rightarrow 0.049 + 0.0493 = 0.0983 \rightarrow \text{SO}_2$$

$$\text{DRY PRODUCT-SUMM.} = 9.4188$$

$$\text{WET PRODUCT} \rightarrow \text{H}_2 \text{ FROM FUEL ONLY}$$

$$\text{H}_2 \rightarrow 0.351 + 0.0442 = 0.3952$$

$$\text{WET PRODUCT-SUMM.} = 9.8140$$

3. EXCESS AIR - 20%, 40%, 60%

$$\text{Additional O}_2 \rightarrow \% \text{ EX. AIR} \times 2.084$$

$$\text{Additional N}_2 \rightarrow \% \text{ EX. AIR} \times 6.920$$

$$\text{Additional WEIGHT} = \text{Add. O}_2 + \text{Add. N}_2$$

TOT. AIR %	Add. WEIGHT	DRY PROD.	WET PROD.
100	0.000	9.4188	9.8140
120	1.8008	11.2196	11.6148
140	3.6016	13.0204	13.4156
160	5.4024	14.8212	15.2164

0: "Tape 1:File 1: Combustion Efficiency Graphs":

```

1: fxd 2;0;r11:csiz 1.5,2,1,0;0;Z;20;N;3;0;dim A$[20];dim B$[20]
2: 150;r11;10;r18
3: ent "Run Number",B$:"DEVCO COAL"0A$
4: 20;Z;ent "C",r0;if Z=40;40;N;12;0
5: ent "H",r1,"S",r2,"N",r3,"O2",r4,"ASH",r5;pen# 1
6: 27.96;r15;r15;r99;429.97;r15;r15;prt A$,B$,"C",r0
7: prt "H",r1,"S",r2,"N",r3,"O2",r4,"Ash",r5,"CV (Btu/lb)"r15;led mode "A"
8: prt " ";fxd 2;gto 39
9: "A":scl 100,r11,0,30;max 0,r18,100,r11,1;var 100,5,0,30,1;100;X;0;Y;100
10: for J=0 to 28 by .25
11: plt 120,J,-2;pen
12: next J
13: plt 100+.25r18,29,1;lbl A$;plt 100+.25r18,3,1;lbl B$
14: plt 128,29,1;lbl "Ultimate Analysis:"
15: plt 128,28.6,1;lbl " "
16: fxd 2;plt 140,29,1;lbl "Carbon: "r0;" "
17: plt 140,28,1;lbl "Hydrogen: "r1;" "
18: plt 140,27,1;lbl "Sulphur: "r2;" "
19: plt 140,26,1;lbl "Nitrogen: "r3;" "
20: plt 140,25,1;lbl "Oxygen: "r4;" "
21: plt 140,24,1;lbl "Ash: "r5;" "
22: plt 140,23,1;lbl "CV (Btu/lb)"r15;fxd 0
23: plt 100+.5r18,-3.5,1;lbl "Total Combustion Air (per cent)"
24: (.02664r0)r12+.07936r10+.009779r21r13+.0114r14r15
25: (.31965X1Y)+X1Y6;(r12+.01r0)8.15711r7
26: (r13+.01r2)5.6036r10;(Y+.01r3)12.813r9;r7/r10r21r13;pen#
27: 4.3197X1r20;.01r0+r12+.01r4Y+.01r24r13r21
28: .01r1+B+r21r22;r8r23+.01r1+B)19.727r23r14
29: csiz 1.5,2,1,90;plt 100+.2r18,8,1;lbl "O2 (percent by vol)";100;1
30: plt C,100r77(r8+.1122(C-100)X+.1281(C-100)Y+.1381(C-100)W)
31: if abs(C-120)>.5;fxd 2;plt 119.8,17.5,1;lbl "O2";2;pen;plt C,7,2
32: C+2;C;gto -2;if C 143;gto +1
33: csiz :iplt 1,-.4,1;lbl "O2";pen;pen# 2
34: csiz 1.5,2,1,90;plt 100+.2r18,8,1;lbl "O2 (percent by vol)";100;1
35: plt C,11.2188X(C-100)+(r8+.1122(C-100)X+.1281Y(C-100)W)
36: if abs(C-120)>.5;plt 119.8,25,1;lbl "O2";W;pen;plt C,W,-2;fxd 0
37: C+2;C;gto -2;if C 143;gto +1
38: csiz :iplt 1,-.4,1;lbl "O2";pen;ret
39: 30;D;pen# 4;100;A;10000;Z;.01;C;11.7r10/r27.35;fxd 1;1000;Z;.1;1
40: csiz 1.5,2,1,90
41: plt 100+.4r18,8,1;lbl "SO2 (percent by vol X)";1;lbl C;1;1;" "
42: plt A,7r10/(r23+.53758r25(A-100))1V
43: if abs(A-120)>.5;fxd 2;plt 121.30,5,1;lbl "SO2";%;pen;plt A,V,-2;fxd 0
44: A+2;A;gto -2;if A 143;gto +1
45: 100;A;.45;B;csiz :if r11 200;.6;B;10;C;60;D;if r11 500;120;B;20;1
46: iplt 1,-.4,1;lbl "SO2"
47: C;1;pen;pen# 1;gto +2;if r11 200;scl 100,r11,0,D;gto +1
48: plt 100+.6r18,C;1;lbl C;imp (C+120)D
49: csiz 1.5,2,1,90;plt 100+.5r18,8,1;lbl "Air & Flue Gas (lb/lb fuel)"
50: plt A,4.13197X+.043197(A-100)X;imp (A+.1r18;A)1.97r11
51: csiz 1.1,2,1,0;iplf 1,-.007D,1;lbl "Dry Air";100;A
52: plt A,r21+.043197X(A-100);imp (A+.1r18;A)1.97r11
53: iplt 1,-.007D,1;lbl "Dry Flue Gas";100;A
54: plt A,r22+.043197(A-100)X;imp (A+.1r18;A)1.97r11
55: iplt 1,.007,1;lbl "Total Flue Gas";csiz
56: dsp "Change Paper (1)";for U=1 to 10;wait 1000;next U;stp
57: 60;D;gsb "A";if r11 200;120;D;if r11 500;240;D
58: scl 100,r11,0,D;0;Z;100;A;pen# 4;csiz :100+.55r18;6
59: plt 100+.5r18,Z,1;lbl Z;imp (Z+D/6)Z)D
60: csiz 1.5,2,1,90;plt G,.2D,1;lbl "Dry & Total Product (cu. m/lb fuel)"
61: plt A,.06243(r23+.53758r25(A-100));imp (A+.2r18;A)1.96r11
62: csiz 1.5,2,1,0;iplt 2,-.9,1;lbl "DFG @ C";100;A
63: plt A,.06243(r24+.53758r25(A-100));imp (A+.2r18;A)1.96r11
64: iplt 2,.6,1;lbl "TFG @ C";100;B;A;212;F

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14: plt 128,29,1;lbl "Ultimate Analysis:"
15: plt 128,28,4,1;lbl "-----"
16: fxd 2;plt 140,29,1;lbl "Carbon: ",r0," %"
17: plt 140,28,1;lbl "Hydrogen: ",r1," %"
18: plt 140,27,1;lbl "Sulphur: ",r2," %"
19: plt 140,26,1;lbl "Nitrogen: ",r3," %"
20: plt 140,25,1;lbl "Oxygen: ",r4," %"
21: plt 140,24,1;lbl "Ash: ",r5," %"
22: plt 140,23,1;lbl "CV(MJ/kg): ",r99;fxd 0
23: plt 100,r1,5,r18,-3.5,1;lbl "Total Combustion Air(per cent)"
24: (.02664r0+r12)+(0.07936r13)+(0.009979r23+r13)-.01r4)r25
25: (.31965X)Y+Xr6;(r12+.01r0)B;.15713r7
26: (r13+.01r2)5.6036r10;(Y+.01r3)12.815r9;r7+r10+r9)r8;pen# 3
27: A+.19/X)r20;.01r0+r12+.01r3+Y+.01r2+r133)r21
28: .01r1+B+r21)r22;r8)r23;(.01r1+B)19.927+r23)r24
29: csiz 1.5,2,1,90;plt 100-.2r18,r8,1;lbl "CO2(percent by vol)":100)C
30: plt C,100r7/(r8+.1122(C-100)X+.1281(C-100)Y))Z;if C=100;Z)r16
31: if abs(C-120)<.5;fxd 2;plt 119.8,17.5,1;lbl "CO2: ",Z;pen:plt C,Z,-2
32: C+2)C;gto -2;if C>143;gto +1
33: csiz :iplt 1,-.4,1;lbl "CO2":pen:pen# 2
34: csiz 1.5,2,1,90;plt 100-.3r18,8,1;lbl "O2(percent by vol)":100)C
35: plt C,11.2188X(C-100)/(r8+.1122(C-100)X+.1281Y(C-100))W
36: if abs(C-120)<.5;plt 119.8,23,1;lbl "O2: ",W;pen:plt C,W,-2;fxd 0
37: C+2)C;gto -2;if C>143;gto +1
38: csiz :iplt 1,-.4,1;lbl "O2":pen:ret
39: C+2)D;pen# 4;f00)A;10000)Z;.01)C;if Zr10/r23>35;fxd 1;1000)Z;.1)C
40: csiz 1.5,2,1,90
41: plt 100-.4r18,8,1;lbl "SO2(percent by vol X":lbl C;lbl ")
42: plt A,Zr10/(r23+.53758r25(A-100))V
43: if abs(A-120)<.5;fxd 2;plt 121,20.5,1;lbl "SO2: ",V;pen:plt A,V,-2;fxd 0
44: A+2)A;gto -2;if A>143;gto +1
45: 100)A;.453B;csiz :if r11>200;.6)B;10)C;60)D;if r11>500;120)D;20)C
46: iplt 1,-.4,1;lbl "SO2"
47: C)I;pen:pen# 1;gto +2;if r11>200;scf 100,r11,0,D;gto +1
48: plt 100-.6r18,C,1;lbl C;imp (C+I)C>D
49: csiz 1.5,2,1,90;plt 100-.5r18,8,1;lbl "Air & Flue Gas(kg/kg fuel)"
50: plt A,4.13197X+.043197(A-100)X;imp (A+.1r18)A>.97r11
51: csiz 1.1,2,1,0;iplt 1,-.007D,1;lbl "Dry Air":100)A
52: plt A,r21+.043197X(A-100);imp (A+.1r18)A>.97r11
53: iplt 1,-.007D,1;lbl "Dry Flue Gas":100)A
54: plt A,r22+.043197(A-100)X;imp (A+.1r18)A>.97r11
55: iplt 1,.007,1;lbl "Total Flue Gas";csiz
56: dsp "Change Paper(1)";for U=1 to 10;wait 1000;next U;stp
57: 60)D;gsb "A";if r11>200;120)D;if r11>500;240)D
58: scf 100,r11,0,D;0)Z;100)A;pen# 4;csiz :100-.55r18)B
59: plt 100-.5r18,2,1;lbl Z;imp (Z+D/6)Z>D
60: csiz 1.5,2,1,90;plt G,.2D,1;lbl "Dry & Total Product(cu m/kg fuel)"
61: plt A,.06243(r23+.53758r25(A-100));imp (A+.2r18)A>.96r11
62: csiz 1.5,2,1,0;iplt 2,-.9,1;lbl "DFG @ C":100)A
63: plt A,.06243(r24+.53758r25(A-100));imp (A+.2r18)A>.96r11
64: iplt 2,.6,1;lbl "TFG @ C":100)B)A;212)F
65: plt A,.06243((r24+.53758r25(A-100))((460+F)/492))Z;gto +2;if Z<D;gto +1
66: A+.2r18)A;gto -1;if A>.96r11;iplt 2,-.2,1;lbl "TFG ".B,".C":gto +1
67: pen;100)A;B+50)B;9B/5+32)F;gto -2;if B>400;gto +1;dsp "Change Paper":20)Z
68: for Q=1 to 10;wait 1000;next Q
69: stp
70: gto 80
71: pen# 1;8)I;30)F;100r7/r8)r16;.35)E;csiz :gsb "A"
72: pen:pen# 4;gto +2;if r11>300;scf r17,r11,0,60;0)F;.55)E;r16)I;gto +1
73: csiz :iplt 100-.5r18,F,1;lbl F;imp (F+10)F>60
74: csiz 1.5,2,1,90;plt 100-.4r18,1,1;lbl "DFBL(percent)":0)B
75: csiz :r12+.01r0+r13+.01r2+Y+.01r3)r14;100)B;50)A;122)D
76: plt B,24D(r14+.01(B-100)(X+Y))/r15)Z;B+10)B;gto +1;if Z>F;pen;gto +2
77: gto -1;if B>.97r11;fxd 0;lbl A;gto +1
78: A+50)A;9A/5+32)D;100)B;gto -2;if A>350;gto +1
79: csiz 1.5,2,1,90;plt r11+.015r18,1,1;lbl "Net Flue Gas Temp(deg
80: "End";end

```

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (ou m/kg fuel)

percent by vol)
CO2 (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

Ultimate Analysis:

Carbon	67.15 %
Hydrogen	4.58 %
Sulphur	3.53 %
Nitrogen	0.76 %
Oxygen	9.27 %
Ash	14.71 %
CV (MJ/kg)	27.98

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu' m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

DEVCO COAL
DC 5

Ultimate Analysis

Carbon	87.88 %
Hydrogen	4.82 %
Sulphur	2.86 %
Nitrogen	0.77 %
Oxygen	8.34 %
Ash	14.81 %
CV (MJ/kg)	27.96

CO₂, 15.23 O₂, 3.56

Total Combustion Air (per cent)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Carbon	87.88 %
Hydrogen	4.82 %
Sulphur	2.86 %
Nitrogen	0.77 %
Oxygen	8.34 %
Ash	14.81 %
CV (MJ/kg)	27.98

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVCO COAL
 DC 8

Ultimate Analysis:

Carbon	85.45 %
Hydrogen	4.44 %
Sulphur	4.53 %
Nitrogen	1.18 %
Oxygen	5.39 %
Ash	19.10 %
CV (MJ/kg)	27.48

Dry & Total Product (on m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Ultimate Analysis

Carbon	65.45 %
Hydrogen	4.44 %
Sulphur	4.53 %
Nitrogen	1.18 %
Oxygen	5.39 %
ash	19.10 %
CV (MJ/kg)	27.48

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

30
 DEVED COAL
 DC 9

Ultimate Analysis

Carbon	85.30 %
Hydrogen	4.43 %
Sulphur	4.77 %
Nitrogen	1.16 %
Oxygen	5.28 %
Ash	18.86 %
CV (MJ/kg)	27.48

CO₂ 14.86 O₂ 3.56
 SO₂ 4.07

Dry & Total Product (on m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

DEVCO COAL
DC 8

CO₂ 14.88 O₂ 3.58

Ultimate Analysis

Carbon	65.38 %
Hydrogen	4.43 %
Sulphur	4.77 %
Nitrogen	1.18 %
Oxygen	5.28 %
Ashe	19.08 %
CV (MJ/kg)	27.48

TFG	400 C
TFG	250 C
TFG	300 C
TFG	250 C
TFG	200 C
TFG	150 C
TFG	100 C
TFG	0 C
DFG	0 C

Total Combustion Air (percent)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVCO COAL
 DC 10

Ultimate Analysis

Carbon	65.12 %
Hydrogen	4.41 %
Sulphur	5.02 %
Nitrogen	1.15 %
Oxygen	5.38 %
Ash	18.81 %
CV (MJ/kg)	27.48

CO₂, 14.95 O₂, 3.56
 SO₂, 4.29

Total Flue Gas
 Dry Flue Gas
 Dry Air

Dry & Total Product (ou m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg Fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVED COAL
 BCC 11

Ultimate Analysis:

Carbon	65.21 %
Hydrogen	4.42 %
Sulphur	4.89 %
Nitrogen	1.16 %
Oxygen	5.37 %
Ash	18.04 %
CV (MJ/kg)	27.48

Dry & Total Product (ou m/kg fuel)

DEVCO COAL
DC 11

CO2, 14.96 O2, 3.56

Ultimate Analyses

Carbon	65.21 %
Hydrogen	4.42 %
Sulphur	4.89 %
Nitrogen	1.16 %
Oxygen	5.37 %
Ash	18.04 %
CV (MJ/kg)	27.48

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (ou m/kg fuel)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 8.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

DEVCO COAL
DC 14

Ultimate Analysis

Carbon	87.28 %
Hydrogen	4.58 %
Sulphur	3.45 %
Nitrogen	0.78 %
Oxygen	0.28 %
Ash	14.71 %
CV (MJ/kg)	27.96

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO2 (percent by vol X 0.01)
 O2 (percent by vol)
 CO2 (percent by vol)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Ultimate Analysis:

Carbon	87.43 %
Hydrogen	4.08 %
Sulphur	3.12 %
Nitrogen	2.76 %
Oxygen	8.31 %
ASH	14.78 %
CV (MJ/kg)	27.98

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVCO COAL
 DC 10

Ultimate Analyzed

Ultimate Analyzed	Carbons	Hydrogens	Sulphurs	Nitrogens	Oxygens	Ashs	CV (MJ/kg)
	87.08 %	4.58 %	3.83 %	2.78 %	9.25 %	14.09 %	27.06

CO₂, 15.17 O₂, 3.56
 SO₂, 3.08

A1-37

Total Combustion Air (per cent)

Dry & Total Product (ou m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol. X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Ultimate Analysis

Carbon	87.21 %
Hydrogen	4.58 %
Sulphur	3.43 %
Nitrogen	8.78 %
Oxygen	2.28 %
Asht SO ₂	14.72 %
CV (MJ/kg)	27.88

Dry & Total Product (cu m/kg fuel)

Ultimate Analysis:

Carbon	67.21 %
Hydrogen	4.59 %
Sulphur	3.43 %
Nitrogen	0.78 %
Oxygen	8.28 %
Ash	14.72 %
CV (MJ/kg)	27.96

TFG	400 C
TFG	350 C
TFG	300 C
TFG	250 C
TFG	200 C
TFG	150 C
TFG	100 C
TFG	0 C
DFG	0 C

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVCO COAL
 DC 21

Ultimate Analysis:

Carbon	68.85 %
Hydrogen	4.57 %
Sulphur	3.82 %
Nitrogen	8.75 %
Oxygen	9.27 %
Ash	14.86 %
CV (MJ/kg)	27.86

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Dry & Total Product (on m/kg fuel)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

BEVCO COAL
 DC 23

Ultimate Analysis

Carbon	68.08 %
Hydrogen	4.58 %
Sulphur	3.63 %
Nitrogen	0.76 %
Oxygen	9.25 %
Ash	14.89 %
CV (MJ/kg)	27.98

A1-45

Total Combustion Air (per cent)

Dry & Total Product (cu m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

DEVCO COAL
 DC 24

Ultimate Analysis:

Carbon	88.28 %
Hydrogen	4.51 %
Sulphur	4.91 %
Nitrogen	0.75 %
Oxygen	0.14 %
Ash	14.48 %
CV (MJ/kg)	27.98

Total Flue Gas
 Dry Flue Gas
 Dry Air

Dry & Total Product (cu m/kg fuel)

A horizontal scale bar with markings at 100, 50, and 15.

Dry & Total Product (ou m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Ultimate Analyses

Carbon	67.00 %
Hydrogen	4.58 %
Sulphur	3.61 %
Nitrogen	0.78 %
Oxygen	9.26 %
Ash	14.70 %
CV (MJ/kg)	27.96

Dry & Total Product (ou m/kg fuel)

O2 (percent by vol)
CO2 (percent by vol)

DC-12 COAL FEED RATE kg/hr APRIL 8/82

COAL FEED

DC-12 COAL FEED RATE kg/hr APRIL 8/82

COAL FEED

Dry & Total Product (ou m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.01)
 O₂ (percent by vol)
 CO₂ (percent by vol)

Ultimate Analysis

Carbon	67.35 %
Hydrogen	4.68 %
Sulphur	3.24 %
Nitrogen	0.78 %
Oxygen	8.29 %
Ash	14.76 %
CV (MJ/kg)	27.98

Dry & Total Product (on m/kg fuel)

O₂ (percent by vol)
CO₂ (percent by vol)

DEVCO COAL
DC 28

Ultimate Analysis

Carbon	87.35 %
Hydrogen	4.88 %
Sulphur	3.24 %
Nitrogen	0.76 %
Oxygen	9.29 %
Asht	14.76 %
CV (MJ/kg)	27.86

A1-56

Total Combustion Air (per cent)

Dry & Total Product (cu m/kg fuel)

Air & Flue Gas (kg/kg fuel)
 SO₂ (percent by vol X 0.1)
 O₂ (percent by vol)
 CO₂ (percent by vol)

APPENDIX A2

COAL FEED RATES GRAPHS

DC-1 COAL FEED RATE MAY 3/82

COAL FEED

DC-1 COAL FEED RATE MAY 3/82

COAL FEED

DC-2 COAL FEED RATE MAY 6/82

COAL FEED

DC-2 COAL FEED RATE MAY 6/82

COAL FEED

DC-3 COAL FEED RATE kg/hr APRIL 15/82

COAL FEED

TIME X 5 min

DC-3 COAL FEED RATE kg/hr APRIL 15/82

COAL FEED

TIME X 5 min

DC-4 COAL FEED RATE kg/hr APRIL 19/82

COAL FEED

DC-4 COAL FEED RATE kg/hr APRIL 19/82

COAL FEED

DC-5 COAL FEED RATE kg/hr APRIL 22/82

DC-5 COAL FEED RATE kg/hr APRIL 22/82

DC-6 COAL FEED RATE kg/hr APRIL 28/82

DC-6 COAL FEED RATE kg/hr APRIL 28/82

DC-7 COAL FEED RATE kg/hr MARCH 1/82

DC-7 COAL FEED RATE kg/hr MARCH 1/82.

DC-8 COAL FEED RATE kg/hr MARCH 3/82

COAL FEED

TIME X 5 min

DC-8 COAL FEED RATE kg/hr MARCH 3/82

COAL FEED

TIME X 5 min

DC-9 COAL FEED RATE kg/hr FEB. 18/82

COAL FEED

TIME X 5 min

DC-9 COAL FEED RATE kg/hr FEB. 18/82

COAL FEED

TIME X 5 min

DC-10 COAL FEED RATE kg/hr FEB. 22/82

DC-10 COAL FEED RATE kg/hr FEB. 22/82

DC-11 COAL FEED RATE kg/hr MARCH 5/82

DC-11 COAL FEED RATE kg/hr MARCH 5/82

DC-12 COAL FEED RATE kg/hr MARCH 22/82

COAL FEED

DC-12 COAL FEED RATE kg/hr MARCH 22/82

COAL FEED

DC-14 CORAL FEED RATE kg/hr MAY 11/82

CORAL FEED

DC-14 CORAL FEED RATE kg/hr MAY 11/82

CORAL FEED

DC-15 COAL FEED RATE kg/hr MARCH 31-82

COAL FEED

DC-15 COAL FEED RATE kg/hr MARCH 31-82

COAL FEED

DC-16 COAL FEED RATE kg/hr APRIL 2/82

COAL FEED

DC-15 COAL FEED RATE kg/hr APRIL 2/82

COAL FEED

DC-17 COAL FEED RATE kg/hr APRIL 8/82

COAL FEED

DC-17 COAL FEED RATE kg/hr APRIL 8/82

COAL FEED

DC-18 COAL FEED RATE kg/hr APRIL 13/82

COAL FEED

DC-18 COAL FEED RATE kg/hr APRIL 13 82

COAL FEED

DC-20 COAL FEED RATE kg/hr APRIL 21/82

COAL FEED

DC-20 COAL FEED RATE kg/hr APRIL 21/82

COAL FEED

DC-21 COAL FEED RATE kg/hr MARCH 24/82

COAL FEED

DC-21 COAL FEED RATE kg/hr MARCH 24/82

COAL FEED

A2-21

DC-22 COAL FEED RATE kg/hr MARCH 29/82

COAL FEED

DC-22 COAL FEED RATE kg/hr MARCH 29/82

COAL FEED

DC-23 COAL FEED RATE kg/hr APRIL 5/82

DC-23 COAL FEED RATE kg/hr APRIL 5/82

A2-23

DC-24 COAL FEED RATE kg/hr APRIL 2, 82

COAL FEED

TIME X 5 min

DC-24 COAL FEED RATE kg/hr APRIL 2, 82

COAL FEED

TIME X 5 min

DC-25 COAL FEED RATE kg/hr MAY 12/82

COAL FEED

DC-25 COAL FEED RATE kg/hr MAY 12/82

COAL FEED

A2-25

DC-26 COAL FEED RATE kg/hr MAY 13/82

COAL FEED

DC-26 COAL FEED RATE kg/hr MAY 11/82

COAL FEED

DC-27 COAL FEED RATE kg/hr MAY 14/82

COAL FEED

TIME X 5 min

DC-27 COAL FEED RATE kg/hr MAY 14/82

COAL FEED

TIME X 5 min

DC-28 COAL FEED RATE kg/hr MAY 12 '82

DC-28 COAL FEED RATE kg/hr MAY 12 '82

COAL FEED RATE kg/hr 24 hrs. TEST

July 5/82

COAL FEED

COAL FEED RATE kg/hr 24 hrs. TEST

COAL FEED

APPENDIX A3

LIMESTONE FEED RATES GRAPHS

3

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

DC-1 LIME FEED RATE kg/hr MAY 3/82

LINE FEED

DC-1 LIME FEED RATE kg/hr MAY 3/82

LINE FEED

DC-2 LIME FEED RATE kg/hr MAY 6/82

LIME FEED

TIME x 5 min

DC-2 LIME FEED RATE kg/hr MAY 6/82

LIME FEED

TIME x 5 min

A3-4

DC-3 LIME FEED RATE kg/hr APRIL 15/82

LIME FEED

TIME X 5 min

DC-3 LIME FEED RATE kg/hr APRIL 15/82

LIME FEED

TIME X 5 min

DC-4 LIME FEED RATE kg/hr APRIL 19/82

LIME FEED

TIME X 5 min

DC-4 LIME FEED RATE kg/hr APRIL 19/82

LIME FEED

TIME X 5 min

A3-6

DC-5 LIME FEED RATE kg/hr APRIL 22/82

LIME FEED

TIME X 5 min

DC-5 LIME FEED RATE kg/hr APRIL 22/82

LIME FEED

TIME X 5 min

A3-7

DC-6 LIME FEED RATE kg/hr APRIL 28/82

LIME FEED

TIME X 5 min

DC-6 LIME FEED RATE kg/hr APRIL 28/82

LIME FEED

TIME X 5 min

A3-8

DC-7 LIME FEED RATE kg/hr MARCH 1/82

LIME FEED

TIME X 5 min

DC-7 LIME FEED RATE kg/hr MARCH 1/82

LIME FEED

TIME X 5 min

DC-8 LIME FEED RATE kg/hr MARCH 3/82

DC-8 LIME FEED RATE kg/hr MARCH 3/82

A3-10

DC-9 LIME FEED RATE kg/hr FEB. 18/82

LIME FEED

TIME X 5 min

DC-9 LIME FEED RATE kg/hr FEB. 18/82

LIME FEED

TIME X 5 min

DC-10 LIME FEED RATE kg/hr FEB 22/82

LINE FEED

DC-10 LIME FEED RATE kg/hr FEB 22/82

LINE FEED

A3-12

DC-11 LIME FEED RATE kg/hr MARCH 5/82

LIME FEED

TIME X 5 min

DC-11 LIME FEED RATE kg/hr MARCH 5-82

LIME FEED

TIME X 5 min

DC-12 LIME FEED RATE kg/hr MARCH 22/82

LIME FEED

TIME X 5 min

DC-12 LIME FEED RATE kg/hr MARCH 22/82

LIME FEED

TIME X 5 min

A3-14

DC-14 LIME FEED RATE kg/hr MAY 11/82

LIME FEED

DC-14 LIME FEED RATE kg/hr MAY 11/82

LIME FEED

DC-15 LIME FEED RATE kg/hr, MARCH 31/82

LIME FEED

TIME X 5 min

DC-15 LIME FEED RATE kg/hr, MARCH 31/82

LIME FEED

TIME X 5 min

DC-16 LIME FEED RATE kg/hr APRIL 2/82

LIME FEED

TIME x 5 min

DC-16 LIME FEED RATE kg/hr APRIL 2/82

LIME FEED

TIME x 5 min

DC-17 LIME FEED RATE kg/hr APRIL 8/82

LIME FEED

TIME X 5 min

DC-17 LIME FEED RATE kg/hr APRIL 8/82.

LIME FEED

TIME X 5 min

A3-18

DC-18 LIME FEED RATE kg/hr APRIL 13/82

DC-18 LIME FEED RATE kg/hr APRIL 13-82

DC-20 LIME FEED RATE kg/hr APRIL 21/82

DC-20 LIME FEED RATE kg/hr APRIL 21/82

DC-21 LIME FEED RATE kg/hr MARCH 24/82

LIME FEED

TIME X 5 min

DC-21 LIME FEED RATE kg/hr MARCH 24/82

LIME FEED

TIME X 5 min

DC-22 LIME FEED RATE kg/hr MARCH 29/82

DC-22 LIME FEED RATE kg/hr MARCH 29/82

DC-23 LIME FEED RATE kg/hr APRIL 5/82

LIME FEED

DC-23 LIME FEED RATE kg/hr APRIL 5/82

LIME FEED

DC-24 LIME FEED RATE kg/hr APRIL 7/82

LIME FEED

TIMEX min

DC-24 LIME FEED RATE kg/hr APRIL 7/82

LIME FEED

TIMEX min

DC-25 LIME FEED RATE kg/hr MAY 12/82

LIME FEED

DC-25 LIME FEED RATE kg/hr MAY 12/82

LIME FEED

A3-25

DC-26 LIME FEED RATE kg/hr MAY 13/82

LIME FEED

TIME X 5 min

DC-26 LIME FEED RATE kg/hr MAY 13/82

LIME FEED

TIME X 5 min

A3-26

DC-27 LIME FEED RATE kg/hr MAY 14/82

LIME FEED

TIME X 5 min

DC-27 LIME FEED RATE kg/hr MAY 14/82

LIME FEED

TIME X 5 min

DC-28 LIME FEED RATE kg/hr MAY 17/82

LIME FEED

TIME X 5 min

DC-28 LIME FEED RATE kg/hr MAY 17/82

LIME FEED

TIME X 5 min

LIME STONE FEED RATE kg/hr 24 hrs. TEST

July 5/82

LIME FEED

LIME STONE FEED RATE kg/hr 24 hrs. TEST

LIME FEED

APPENDIX A4

GRAPHS of MEASURED OXYGEN

A4-2

DC-1 02 MAY 3/82

02

DC-1 02 MAY 3/82

20

A4-3

DC-2 02 MAY 6/82

02

\ TIME X 5 min

DC-3 02 MAY 6/82

02

TIME X 5 min

A4-4

DC-3 02 APRIL 15/82

02

TIME X 5 min

DC-3 02 APRIL 15/82

02

TIME X 5 min

DC-4 O2 % APRIL 19782

O2 %

TIME x 5 min

DC-4 O2 % APRIL 19782

O2 %

TIME x 5 min

A4-6

DC-5 O2 % APRIL 22-82

O2 %

TIME x 5 min

DC-5 O2 % APRIL 22-82

O2 %

TIME x 5 min

A4-7

DC-6 O2 % APRIL 28/82

DC-6 O2 % APRIL 28/82

A4-8

DC-7 02 % MARCH 1982

02 %

TIME X 5 min

DC-7 02 % MARCH 1982

02 %

TIME X 5 min

A4-9

DC-8 O2 % MARCH 3/82

O2 %

TIME X 5 min

DC-8 O2 % MARCH 3/82

O2 %

TIME X 5 min

A4-10

DC-9 02 % FEB 18/82

02 %

TIME x 5 min

DC-9 02 % FEB 18/82

02 %

TIME x 5 min

DC-10 O₂ % FEB. 22/82O₂ % DC-10 O₂ % FEB. 22/82O₂ %

A4-12.

DC-11 02 1/2 MARCH 5/82

02

TIME X 5 min

DC-11 02 1/2 MARCH 5/82

02

TIME X 5 min

A4-13

DC-12 02 % MARCH 22/82

02 %

TIME x 5 min

DC-12 02 % MARCH 22/82

02 %

TIME x 5 min

DC-14 02 % MAY 11/82

02 %

TIME X 5 min

DC-14 02 % MAY 11/82

02 %

TIME X 5 min

A4-15

DC-15 O2 % MARCH 31 1982

O2 %

TIME x 5 min

DC-15 O2 % MARCH 31 1982

O2 %

TIME x 5 min

A4-16

DC-16 02 % APRIL 2/82

DC-16 02 % APRIL 2/82

A4-17

DC-17 02 % APRIL 8 '82

02 %

TIME X 5 min

DC-17 02 % APRIL 8 '82

02 %

TIME X 5 min

A4-18

DC-18 O2 % APRIL 13/82

O2 %

TIME x 5 min

DC-18 O2 % APRIL 13/82

O2 %

TIME x 5 min

DC-20 O2 % APRIL 21/82

O2 %

TIME X 5 min

DC-20 O2 % APRIL 21/82

O2 %

TIME X 5 min

A4-20

DC-21 02 % MARCH 24/82

02 %

DC-21 02 % / MARCH 24/82

02 %

DC-22 O2 % MARCH 29-82

O2 %

TIME X 5 min

DC-22 O2 % MARCH 29-82

O2 %

TIME X 5 min

DC-23 02 : APRIL 5/82

DC-23 02 : APRIL 5/82

A4-23

DC-24 02 % APRIL 7/82

TIME X 5 min

DC-24 02 % APRIL 7/82

TIME X 5 min

A4-24

DC-25 02 4 MAY 12 1982

02 %

TIME x 5 min

DC-25 02 4 MAY 12 1982

02 %

TIME x 5 min

A4-25

DC-26 O2 % MAY 13/82

O2 %

TIME X 5 min

DC-26 O2 % MAY 13/82

O2 %

TIME X 5 min

A4-26

DC-27 02 MAY 14-82

02

TIME x 5 min

DC-27 02 MAY 14-82

02

TIME x 5 min

A4-27

DC-28 O2 % MAY 7/82

O2 %

TIME X 5 min

DC-28 O2 % MAY 7/82

O2 %

TIME X 5 min

101 OXYGEN 24 hr TEST

July 5/82

OXYGEN

101 OXYGEN 24 hr TEST

OXYGEN

Variable	N	MEAN	VARIANCE	DEVIATION	VARIATION
INEX2 min	578	288.63720	28023.20799	167.40134	57.99715
XYGEN	578	3.37405	.81922	.90511	26.82559

CORRELATION = .08924

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	472.69072664			
1	3.76409095	4.6235726892	(1,576)	
	.0079631157			

degree of regression ($k=1$) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .00796
 STANDARD ERROR OF ESTIMATE = .902279747377

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	577	472.690727		
REGRESSION	1	3.764091	3.764091	
6236				
1		3.764091	3.764091	
6236				
RESIDUAL	576	468.926636	.814109	

confidence coefficient (e.g., 90.95.99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	3.23479	.323478551515E+01	.07485	43.21
X 1	.00048	.482484340537E-03	.00022	2.15

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	3.23479	3.08773
X 1	.00048	.00004

Plot regression curve on present graph ?

101 OXYGEN 24 hr TEST JULY 19

OXYGEN

101 OXYGEN 24 hr TEST JULY 19

OXYGEN

VARIABLE.	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
OXYGEN	629	3.74388	1.66393	1.28993	34.45449

CORRELATION = .27235

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	1044.94893482			
X 1	77.50903863	50.2337844581		(1.627)
	.0741749535			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .07417
 STANDARD ERROR OF ESTIMATE = 1.24216196271

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	1044.948935		
REGRESSION	1	77.509039	77.509039	
0.2338				
X 1	1	77.509039	77.509039	
0.2338				
RESIDUAL	627	967.439896	1.542966	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	3.13490	.313490071188E+01	.09917	31.61
X ¹	.00193	.193326495687E-02	.00027	7.09

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	2.94010	3.32970
X ¹	.00140	.00247

Plot regression curve on present graph ?

APPENDIX A5

GRAPHS of MEASURED SULPHUR DIOXIDE

DC-1 SO2 MAY 3/82

DC-1 SO2 MAY 3/82

A5-3

DC-2, 502 MAY 6/82

502

TIMEX5 min

DC-2, 502 MAY 5/82

502

TIMEX5 min

A5-4

DC-3 SO APRIL 15/82

SO

TIME X 5 min

DC-3 SO APRIL 15/82

SO

TIME X 5 min

A5-4 0.

DC-4 SO2 ppm APRIL 1982

DC-4 SO2 ppm APRIL 1982

DC-5 SO2 ppm APRIL 22/82.

DC-5 SO2 ppm APRIL 22/82

A5-6

DC-6 SO2 ppm APRIL 28 1982

TIME X 5 min

DC-6 SO2 ppm APRIL 28 1982

TIME X 5 min

A5-7

DC-7 SO2 ppm MARCH 1/82

DC-7 SO2 ppm MARCH 1/82

A5-8

DC-8 SO2 ppm MARCH 3 1982

DC-8 SO2 ppm MARCH 3 1982

DC-9 SO2 ppm FEB. 18/82

SO2 ppm

TIME X 5 min

DC-9 SO2 ppm FEB. 18/82

SO2 ppm

TIME X 5 min

A5-10

DC-10 SO2 ppm FEB. 22 82

DC-10 SO2 ppm FEB. 22 82

DC-11 SO2 ppm MARCH 5/82

DC-11 SO2 ppm MARCH 5/82

DC-12 SO2 ppm MARCH 22-82

DC-12 SO2 ppm MARCH 22-82

DC-14 SO2 ppm MAY 11/82

SO2 ppm

TIME X 5 min

DC-14 SO2 ppm MAY 11/82

SO2 ppm

TIME X 5 min

A5-14

DC-15 SO2 ppm MARCH 31/82

DC-15 SO2 ppm MARCH 31/82

DC-15 NO ppm MARCH 31/82

DC-16 SO2 ppm APRIL 2/82

SO2 ppm

TIME X5 min

DC-16 SO2 ppm APRIL 2/82

SO2 ppm

TIME X5 min

A5-17

DC-17 SO2 ppm APRIL 8 82

SO2 ppm

TIME x 5 min

DC-17 SO2 ppm APRIL 8 82

SO2 ppm

TIME x 5 min

DC-18 SO2 ppm APRIL 13/82

DC-18 SO2 ppm APRIL 13/82

DC-20 SO₂ ppm APRIL 21/82SO₂ ppm

TIME X 5 min

DC-20 SO₂ ppm APRIL 21/82SO₂ ppm

TIME X 5 min

DC-21 SO2 ppm MARCH 24/82

DC-21 SO2 ppm MARCH 24/82

A5-21

DC-22 SO2 ppm MARCH 29 82

SO2 ppm

TIME X 5 min

DC-22 SO2 ppm MARCH 29 82

SO2 ppm

TIME X 5 min

UC-23 SO2 ppm APRIL 5/82

UC-23 SO2 ppm APRIL 5/82

DC-24 SO2 ppm APRIL 7 82

SO2 ppm

TIME X 5 min

DC-24 SO2 ppm APRIL 7 82

SO2 ppm

TIME X 5 min

A5-24

DC-25 SO2 ppm MAY 12/82

SO2 ppm

DC-25 SO2 ppm MAY 12/82

SO2 ppm

A5-25

DC-26 SO2 ppm MAY 13/82

DC-26 SO2 ppm MAY 13/82

DC-SO₂ ppm MAY 14/82

A5-27

DC-28 SO2 ppm MAY 7-82

DC-28 SO2 ppm MAY 7-82

A5-28

216 SO2 24 hr TEST

July 5/82

SO2 ppm

216 SO2 24 hr TEST

SO2 ppm

A5-29

24 hr TEST July 5/82

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	577	288.05893	27871.12499	166.94647	57.95567
SO2 ppm	577	735.11265	182037.87791	426.65897	58.03994

CORRELATION = -.14394

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	104853817.67764300			
X ¹	2172525.45465171	12.1658201741	1	(1.575)
	.0207195647			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .02072
 STANDARD ERROR OF ESTIMATE = 422.582726088

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	576	104853817.677643		
REGRESSION	1	2172525.454652	2172525.454652	
X ¹	1	2172525.454652	2172525.454652	
RESIDUAL	575	102681292.222991	178575.160388	

Confidence coefficient (e.g., 90.95.99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	841.08078	.841080784441E+03	35.10707	23.96
X ¹	-.36787	-.367869638544E+00	.10547	-3.49

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	841.08078	772.11183
X ¹	-.36787	-.57507
		910.04974
		-.16067

Plot regression curve on present graph ?

216 502 24hr TEST JULY 19

502

TIME X2 min

216 502 24hr TEST JULY 19

502

TIME X2 min

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.01590	33018.51886	181.70999	57.68280
SQ2	629	652.86169	192027.78498	438.20975	67.12138

CORRELATION = -.29633

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	120593448.96661400			
X 1	10589711.83976370		60.3593068468	(1,627)
	0878133259			

Degree of regression (≤ 1) = 2

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .08781
 STANDARD ERROR OF ESTIMATE = 418.861023278

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	120593448.966614		
REGRESSION	1	10589711.839764	10589711.839764	
X 1	1	10589711.839764	10589711.839764	
RESIDUAL	627	110003737.126850	175444.556821	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	877.98264	.877982643025E+03	33.44481	26.25
X ¹	-.71463	-.714633639319E+00	.09198	-7.77

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	877.98264	812.29075	943.67454
X ¹	-.71463	-.89531	-.53396

Plot regression curve on present graph ?

APPENDIX A6

- GRAPHS of MEASURED CARBON DIOXIDE

16-2

DC-1 CO2 MAY 3/82

CO2

TIME (5 mn)

DC-1 CO2 MAY 3/82

CO2

TIME (5 mn)

A6-3

DC-2 CO2 MAY 6/82

DC-2 CO2 MAY 6/82

DC-3 CO2 APRIL 15 82

CO2

TIME X 5 min

DC-3 CO2 APRIL 15 82

CO2

TIME X 5 min

4

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

A6-5

DC-4 CO2 % APRIL 19 82

TIME X 5 min

DC-4 CO2 % APRIL 19 82

TIME X 5 min

A6-6

DC-5 CO2 % APRIL 22/82

CO2 %

TIME X 5 min

DC-5 CO2 % APRIL 22/82

CO2 %

TIME X 5 min

A6-7

DC-6 CO2 4 APRIL 28/82

CO2 %

TIME X 5 min

DC-6 CO2 5 APRIL 28/82

CO2 %

TIME X 5 min

A6-8

DC-7 CO₂ % MARCH 1/82

CO₂ %

TIME x 5 min

DC-7 CO₂ % MARCH 1/82

CO₂ %

TIME x 5 min

A6-9

DC-8 CO2 % MARCH 3/82

DC-8 CO2 % MARCH 3/82

A6-10

DC-9 CO2 % FEB. 18/82 A.

CO2 %

TIME X 5 min

DC-9 CO2 % FEB. 18/82

CO2 %

TIME X 5 min

A8-11

DC-10 CO2 % FEB. 22 82

DC-10 CO2 % FEB. 22 82

DC-11 CO2 % MARCH 5/82

DC-11 CO2 % MARCH 9/82

DC-12 CO2 % MARCH 22/82

DC-12 CO2 % MARCH 22/82

A6-14

DC-14 CO2 % MAY 11/82

CO2 %

TIME X 5 min

DC-14 CO2 % MAY 11/82

CO2 %

TIME X 5 min

A6-15

DC-15 CO2 % MARCH 31-82

CO2 %

TIME x 5 min.

DC-15 CO2 % MARCH 31-82

CO2 %

TIME x 5 min.

A6-16

DC-18 CO2 % APRIL 24/82

DC-18 CO2 % APRIL 24/82

A6-17

DL-17 CO2 % APRIL 8-82

CO2 %

DL-17 CO2 % APRIL 8-82

CO2 %

A6-18

DC-18 CO2 % APRIL 13/82

TIME x 5 min

DC-18 CO2 % APRIL 13/82

TIME x 5 min

A6-19

DC-20 CO2 ppm APRIL 21/82

CO2 ppm

TIME X 5 min

DC-20 CO2 ppm APRIL 21/82

CO2 ppm

TIME X 5 min

A6-20

DC-21 CO2 % MARCH 24/82

CO2 %

TIME X 5 min

DC-21 CO2 % MARCH 24/82

CO2 %

TIME X 5 min

A6-21

DC-22 CO2 % MARCH 29/82

DC-22 CO2 % MARCH 29/82

A6-22

DC-23 CO2 % APRIL 5/82

DC-23 CO2 % APRIL 5/82

A6-23

DC-24 CO2 % APRIL 7 82

DC-24 CO2 % APRIL 7 82

A6-24

DC-25 CO2 % MAY 12/82

TIME X 5 min

DC-25 CO2 % MAY 12/82

TIME X 5 min

A6-25

DC 26 CO2 % MAY 13/82

CO2 %

TIME x 5 min

DC 26 CO2 % MAY 13/82

CO2 %

TIME x 5 min

A6-26

DC-27 CO2 % MAY 14/82

DC-27 CO2 % MAY 14/82

A6-27

DC-28 CO2 % MAY 7/82

CO2 %

TIME X 5 min

DC-28 CO2 % MAY 7/82

CO2 %

TIME X 5 min

16-28

103 CO2 (%) 24 hr TEST

July 5/82

CO2 %

103 CO2 (%) 24 hr TEST

CO2 %

A6-29
246 test July 5/82

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	577	288.82669	27786.23380	166.69203	57.71351
CO2 %	577	14.81768	2.60601	1.61431	10.89451

CORRELATION = -.12879

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R 2 (CUMULATIVE)
TOTAL (ADJ)	1501.05968804			
X 1	24.89908816	9.6987927284		(1.575)
	.0165876736			

Degree of regression (≤ 1) = 2

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .01659
STANDARD ERROR OF ESTIMATE = 1.60225960003

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	576	1501.059688		
REGRESSION	1	24.899088	24.899088	
X 1	1	24.899088	24.899088	
RESIDUAL	575	1476.160600	2.567236	

Confidence coefficient (e.g., 90, 95, 99) = 7

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
CONSTANT	15.17793	.151779267888E+02	.13353	113.67
X 1	.00125	-.124728482026E-02	.00040	-3.11

95 % CONFIDENCE INTERVAL

A6-30

COEFFICIENT

LOWER LIMIT

UPPER LIMIT

CONSTANT

15.17793

14.91560

15.44025

X¹

-.00125

-.00203

-.00046

Plot regression curve on present graph ?

103 CO2 24 hr TEST JULY 19 82

CO2

TIME*2 min

103 CO2 24 hr TEST JULY 19 82

CO2

TIME*2 min

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
CO2	629	14.62957	5.04795	2.24676	15.35769

CORRELATION = .11465

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	3170.10998410			
X-1	41.67294186	8.3520729978		(1.627)
	.0131455824			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .01315
 STANDARD ERROR OF ESTIMATE = 2.23372620586

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	3170.109984		
REGRESSION	1	41.672942	41.672942	
8.3521				
X-1	1	41.672942	41.672942	
8.3521				
RESIDUAL	627	3128.437042	4.989533	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T-VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	14.18304	.141830384900E+02	.17834	79.53
X-1	.00142	.141756272142E-02	.00049	2.89

A6-33

COEFFICIENT

95 % CONFIDENCE INTERVAL

LOWER LIMIT

UPPER LIMIT

CONSTANT
X 1

14.18304
.00142

13.83274
.00045

14.53333
.00238

Plot regression curve on present graph

APPENDIX A7

GRAPHS of MEASURED CARBON MONOXIDE

DC-1 CO MAY 3/82

TIME (5 min)

DC-1 CO MAY 3/82

TIME (5 min)

A7-3

DC-2 CO MAY 6/82

CO

TIMEX5 min

DC-2 CO MAY 6/82

CO

TIMEX5 min

DC-3 CO APRIL 15-82

DC-3 CO APRIL 15-82

A7-5

DC-4 CO ppm APRIL 19/82

CO ppm

TIME X 5 min

DC-4 CO ppm APRIL 19/82

CO ppm

TIME X 5 min

A7-6.

DC-5 CO ppm APRIL 22/82

CO ppm

TIME X 5 min

DC-5, CO ppm APRIL 22/82

CO ppm

TIME X 5 min

A7-7

DC-6 CO ppm APRIL 28/82

DC-6 CO ppm APRIL 28/82

A7-8

DC-7 CO ppm MARCH 1/82

DC-7 CO ppm MARCH 1/82

A7-9

DC-8 CO ,ppm MARCH 3/82

CO ppm

TIME X 5 min

DC-8 CO ppm MARCH 3/82

CO ppm

TIME X 5 min

A7-10

DC-9 CO ppm FEB. 1982

CO ppm

TIME X 5 min

DC-9 CO ppm FEB. 1982

CO ppm

TIME X 5 min

A7-11

DC-10 CO ppm FEB. 22/82

DC-10 CO ppm FEB. 22/82

DC-11 CO ppm MARCH 5/82

DC-11 CO ppm MARCH 5/82

A7-13

DC-12 CO ppm MARCH 22/82

CO ppm

TIME X 5 min

DC-12 CO ppm MARCH 22/82

CO ppm

TIME X 5 min

A7-14

DC-14 CO ppm MAY 11-82

CO ppm

TIME X 5 min

DC-14 CO ppm MAY 11-82

CO ppm

TIME X 5 min

AT-15

DC-15 CO ppm MARCH 31/82

DC-15 CO ppm MARCH 31/82

A7-16

DC-15 CO ppm APRIL 2-82

CO ppm

DC-15 CO ppm APRIL 2-82

CO ppm

A7-17

DC-17 CO ppm APRIL 8/82

DC-17 CO ppm APRIL 8/82

A7-18

DC-18 CO ppm APRIL 13-82

CO ppm

TIME X 5 min

DC-18 CO ppm APRIL 13-82

CO ppm

TIME X 5 min

DC-20 CO ppm APRIL 21/82

TIME X 5 min

DC-20 CO ppm APRIL 21/82

TIME X 5 min

DC-21 CO ppm MARCH 24/82

DC-21 CO ppm MARCH 24/82

A7-21

DC-22 CO ppm MARCH 29/82

DC-22 CO ppm MARCH 29/82

A7-22

-DC-23 CO ppm

DC-23 CO ppm

A7-23

DC-24 CO ppm APRIL 7/82

DC-24 CO ppm APRIL 7/82

A7-24

DC-25 CO ppm MAY 12/82

CO ppm

TIME x 5 min

DC-25 CO ppm MAY 12/82

CO ppm

TIME x 5 min

A7-25

DC-26 CO ppm MAY 13/82

DC-26 CO ppm MAY 13/82

BC-27 CO ppm MAY 14 82

CO ppm

TIME X 5 min

BC-27 CO ppm MAY 14 82

CO ppm

TIME X 5 min

A7-27

DC-28 CO ppm MAY 7-82

CO ppm

TIME x 5 min

DC-28 CO ppm MAY 7-82

CO ppm

TIME x 5 min

102 CO 24 hr TEST

July 5/82

102 CO 24 hr TEST

24 hr test July 5/82

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	577	289.00000	27792.16667	166.70983	57.68506
CD	577	1175.87522	790881.56774	889.31522	75.63007

CORRELATION = -.64893

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	455547783.01559800			
X 1	191838446.26124300	418.2904858730		(1.575)
	.4211159694			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .42112
STANDARD ERROR OF ESTIMATE = 677.218527128

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	576	455547783.015598		
REGRESSION	1	191838446.261243	191838446.261243	418.2905
X 1	1	191838446.261243	191838446.261243	418.2905
RESIDUAL	575	263709336.754355	458624.933486	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
CONSTANT	2176.32023	217632022675E+04	56.45932	38.55
X 1	-3.46175	-346174743983E+04	16926	-20.45

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T-VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	2176.32023	.217632022675E+04	56.45932	38.55
X 1	-3.46175	-.346174743983E+01	.16926	-20.45

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	2176.32023	2065.40411	2287.23635
X 1	-3.46175	-3.79427	-3.12923

Plot regression curve on present graph. ?

102 CO 24hr TEST JULY 19

CO

TIMEX2 min

102 CO 24hr TEST JULY 19

CO

TIMEX2 min

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIME X2 min	629	315.00000	33022.50000	181.72094	57.68919
CO	629	1067.48808	802954.50822	896.07729	83.94261

CORRELATION = -.43686

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ.)	504255431.16057200			
X 1	96235439.04814920	147.8839798285		(1.627)
	1908466089			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .19085
 STANDARD ERROR OF ESTIMATE = 806.690516057

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	504255431.160572		
REGRESSION	1	96235439.048149	96235439.048149	1
7.8840				
X 1	1	96235439.048149	96235439.048149	1
7.8840				
RESIDUAL	627	408019992.112423	650749.588696	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T-VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	1746.05592	.174605591729E+04	64.40650	27.11
X 1	-2.15418	-.215418362215E+01	.17714	-12.16

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	1746.05592	1619.54946	1872.56237
X 1	-2.15418	-2.50212	-1.80624

Plot regression curve on present graph ?

APPENDIX A8

GRAPHS of MEASURED NITRIC OXIDE

A8-2

DC-1 NO MAY 3/82

NO

TIME (5 mn)

DC-1 NO MAY 3/82

NO

TIME (5 mn)

DC-2 NO MAY 6 1982

NO

DC-2 NO MAY 6 1982

NO

DC-3 NO APRIL 15/92

NO

DC-3 NO APRIL 15/92

NO

A8-5

DC-4 NO ppm APRIL 19782

DC-4 NO ppm APRIL 19782

DC-5 NO ppm APRIL 22/82

DC-5 NO ppm APRIL 22/82

A8-7

DC-6 NO ppm APRIL 28 82

NO ppm

TIME x 5 min

DC-6 NO ppm APRIL 23 82

NO ppm

TIME x 5 min

DC-2 NO ppm MARCH 1-62

DC-2 NO ppm MARCH 1-62

18-9

DC-8 NO ppm MARCH 3 '82

DC-8 NO ppm MARCH 3 '82

QC-9 NO ppm FEB. 1982

QC-9 NO ppm FEB. 1982

A8-11

DC-10 NO ppm FEB. 22/82

DC-10 NO ppm FEB. 22/82

A8-12

DC-11 NO ppm MARCH 5/82

TIME X 5 min

DC-11 NO ppm MARCH 5/82

TIME X 5 min

EC-12 NO ppm MARCH 22/82

EC-12 NO ppm MARCH 22/82

DC-14 NO ppm MAY 11/82

DC-14 NO ppm MAY 11/82

DE-15 NO ppm MARCH 31/82

DE-15 NO ppm MARCH 31/82

DC-16 NO ppm APRIL 2/82

NO ppm

TIMEX5 min

DC-16 NO ppm APRIL 2/82

NO ppm

TIMEX5 min

UC-17 NO ppm APRIL 8/82

NO

TIME x 5 min

UC-17 NO ppm APRIL 8/82

NO

TIME x 5 min

A8-18

DC-18 NO ppm APRIL 13/82

TIME X 5 min

DC-18 NO ppm APRIL 18/82

TIME X 5 min

DC-20 NO ppm APRIL 21-82

DC-20 NO ppm APRIL 21-82

A8-20

DC-21 NO ppm MARCH 24/82

DC-21 NO ppm MARCH 24/82

NO ppm

DC-22 NO ppm MARCH 29 82

NO ppm

TIME x 5 min

DC-22 NO ppm MARCH 29 82

NO ppm

TIME x 5 min

A8-22

DC-23 NO ppm APRIL 5/82

DC-23 NO ppm APRIL 5/82

18-23

DC-24 NO ppm APRIL 7-82

NO ppm

TIME (min)

DC-24 NO ppm APRIL 7-82

NO ppm

TIME (min)

A8-24

DC-25 NO ppm MAY 12/82

DC-25 NO ppm MAY 12/82

A8-25-

DC-26 NO ppm MAY 13-82

DC-26 NO ppm MAY 13-82

DC-27 NO ppm MAY 14/82

DC-27 NO ppm MAY 14/82

A8-27

DC-28 NO ppm MAY 7-82

NO ppm

TIME X5 min

DC-28 NO ppm MAY 7-82

NO ppm

TIME X5 min

A8-28

105 NO 24 hr TEST

July 5/62

105 NO 24 hr TEST

24.42 TEST July 5/82

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2.min	577	289.00000	27792.16667	166.70983	57.68506
NO	577	259.56672	3058.70084	55.30552	21.30688

CORRELATION = .17291

PRELIMINARY ADJ

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	1761811.68110918			
X 1	52677.39373504	17.7221308012	(1,575)	
	.0298995598			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
R-SQUARED = .02990
STANDARD ERROR OF ESTIMATE = 54.5197895842

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	576	1761811.681109		
REGRESSION	1	52677.393735	52677.393735	
7.7221				
X 1	1	52677.393735	52677.393735	
7.7221				
RESIDUAL	575	1709134.287374	2972.407456	

Confidence coefficient (e.g., 90,95,99) = ?

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
CONSTANT	242.98852	.242988518198E+03	4.54528	53.46
X 1	.05736	.573640354296E-01	.01363	4.21

95 % CONFIDENCE INTERVAL

A8030

COEFFICIENT

LOWER LIMIT

UPPER LIMIT

CONSTANT
X⁻¹

242.98852
.05736

234.05916
.03059

251.91787
.08413

Plot regression curve on present graph ?

105 NO 24 hr TEST JULY 19

NO

105 NO 24 hr TEST JULY 19

NO

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
NO.	629	358.65183	19976.88018	141.33959	39.40858

CORRELATION = .17870

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	12545480.75039750			
X ¹	400601.33027154	20.6817231684		(1.627)
	.0319319234			

Degree of regression (≤ 1) = ?

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .03193
 STANDARD ERROR OF ESTIMATE = 139.175513782

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	12545480.750397		
REGRESSION	1	400601.330272	400601.330272	20.6817
X ¹	1	400601.330272	400601.330272	20.6817
RESIDUAL	627	12144879.420126	19369.823637	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	314.87120	.314871203913E+03	11.11183	28.34
X 1	.13899	.138986109162E+00	.03056	4.55

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	314.87120	293.04548	336.69692
X 1	.13899	.07896	.19902

Plot regression curve on present graph ?

APPENDIX A9

GRAPHS of MEASURED BED TEMPERATURE

DC-1 BED TEMPERATURE C

BED TEMP

TIME X 5 min

DC-1 BED TEMPERATURE C

BED TEMP

TIME X 5 min

5

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

A9-3

DC-2 BED TEMPERATURE

BED TEMP

DC-2 BED TEMPERATURE

BED TEMP

DC-3 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-3 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

A9-5

DC-4 BED TEMPERATURE °C

DC-4 BED TEMPERATURE °C

DC-5 BED TEMPERATURE °C

BED TEMP

DC-5 BED TEMPERATURE °C

BED TEMP

A9-7

DC-6 BED TEMPERATURE °C

DC-6 BED TEMPERATURE °C

A9-8

DC-7 BED TEMPERATURE °C

BED TEMP

TIME 10 min

DC-7 BED TEMPERATURE °C

BED TEMP

TIME 10 min

A9-9.

DC-8 BED TEMPERATURE

BED TEMP

TIME x 10 min

DC-8 BED TEMPERATURE

BED TEMP

TIME x 10 min

DC-9 BED TEMPERATURE °C

DC-9 BED TEMPERATURE °C

A9-11

DC-10 BED TEMPERATURE °C

BED TEMP

DC-10 BED TEMPERATURE °C

BED TEMP

A9-12

DC-11 BED TEMPERATURE °C

BED TEMP

TIME X 10 min

DC-11 BED TEMPERATURE °C

BED TEMP

TIME X 10 min

A9-13

DC-12 BED TEMPERATURE °C

BED TEMP

DC-12 BED TEMPERATURE °C

BED TEMP

A9-14

DC-14 BED TEMPERATURE °C

DC-14 BED TEMPERATURE °C

A9-15

DC-15 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-15 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

A9-16

DC-16 BED TEMPERATURE °C

BED TEMP

DC-16 BED TEMPERATURE °C

BED TEMP

A9-17

DC-17 BED TEMPERATURE C

BED TEMP

DC-17 BED TEMPERATURE C

BED TEMP

A9-18

DC-18 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-18 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-20 BED TEMPERATURE °C

BED TEMP

DC-20 BED TEMPERATURE °C

BED TEMP

A9-20

DC-21 BED TEMPERATURE °C

BED TEMP

DC-21 BED TEMPERATURE °C

BED TEMP

DC-22 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-22 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

A9-22

DC-23 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

DC-23 BED TEMPERATURE °C

BED TEMP

TIME X 5 min

A9-23

DC-24 BED TEMPERATURE °C

BED TEMP

DC-24 BED TEMPERATURE °C

BED TEMP

A9-24

DC-25 BED TEMPERATURE °C

BED TEMP

DC-25 BED TEMPERATURE °C

BED TEMP

A9-25

DC-26 BED TEMPERATURE °C

BED TEMP

DC-26 BED TEMPERATURE °C

BED TEMP

DC-27 BED TEMPERATURE °C

DC-27 BED TEMPERATURE °C

A9-27

DC-28 BED TEMPERATURE

BED TEMP

TIME X 5 min

DC-28 BED TEMPERATURE

BED TEMP

TIME X 5 min

A9-28

108 TEMP 2, 24 hr TEST

July 5/82

TEMP 2

108 TEMP 2, 24 hr TEST

TEMP 2

A9-29

113 TEMP 7, 24 hr TEST

July 5/82

TEMP 7

113 TEMP 7, 24 hr TEST

TEMP 7

24 hr A9-30 July 5/82
TEST

VARIABLE	N	MEAN	VARIANCE	DEVIATION	VARIATION
TIMEX2 min	613	307.00000	31365.16667	177.10214	57.6879
TEMP 2	613	676.25015	115647.50197	340.06985	50.2875

CORRELATION = -.45545

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	70776271.20608690			
X 1	14681591.04757040		159.9162720015	(1.611)
	.2074366281			

Degree of regression (<= 1) = 2

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	612	70776271.206087		
REGRESSION	1	14681591.047570	14681591.047570	1
X 1	1	14681591.047570	14681591.047570	
RESIDUAL	611	56094680.158516	91807.987166	

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
CONSTANT	944.73848	.944738484470E+03	24.50595	38.55
X 1	-.87455	-.874554845770E+00	.06916	-12.65

Confidence coefficient (e.g., 90,95,99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	944.73848	.944738484470E+03	24.50595	38.55
X ¹	-.87455	-.874554845770E+00	.06916	-12.68

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	896.60176	992.87521
X ¹	-1.01040	-.73871

Plot confidence interval of regression line also?

108 TEMP2 24 hr TEST JULY 19

108 TEMP2 24 hr TEST JULY 19

A9-33

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
TEMP 2	629	861.70572	1543.16892	39.28319	4.55877

CORRELATION = -.20987

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	969110.07939512			
X ¹	42683.47192220	28.8879191070		(1.627)
	.0440439872			

Degree of regression (≤ 1) = 2

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .04404
 STANDARD ERROR OF ESTIMATE = 38.4389697318

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	969110.079395		
REGRESSION	1	42683.471922	42683.471922	
8.8879				
X ¹		42683.471922	42683.471922	
8.8879				
RESIDUAL	627	926426.607473	1477.554398	

Confidence coefficient (e.g., 90, 95, 99) = ?

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	875.99649	.875996493271E+03	3.06898	285.44
X ¹	-.04537	-.453675234942E-01	.00844	-5.37

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	875.99649	869.96843
X ¹	-.04537	-.06195
		882.02455
		-.02879

Plot regression curve on present graph ?

113 TEMP? 24hr TEST JULY 19

TEMP ?

115 TEMP? 24hr TEST JULY 19

TEMP ?

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
TIMEX2 min	629	315.00000	33022.50000	181.72094	57.68919
TEMP 7	629	861.26763	52.75091	7.26298	.84929

CORRELATION = -.00929

PRELIMINARY AOV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	33127.57057106			
X 1	2.86171827			(1.627)
	.0000863848			

Degree of regression (≤ 1) = 2

SELECTED DEGREE OF REGRESSION = 1
 R-SQUARED = .00009
 STANDARD ERROR OF ESTIMATE = 7.26845765203

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	628	33127.570571		
REGRESSION	1	2.861718	2.861718	
.0542				
X 1	1	2.861718	2.861718	
.0542				
RESIDUAL	627	33124.708853	52.830477	

Confidence coefficient (e.g., 90, 95, 99) = ?

A9-37

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR	T-VALUE
	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	
CONSTANT	861.38465	.861384645530E+03	.58032	1484.34
X 1	-.00037	-.371474187879E-03	.00160	7.23

	COEFFICIENT	95 % CONFIDENCE INTERVAL	
		LOWER LIMIT	UPPER LIMIT
CONSTANT	861.38465	860.24479	862.52450
X 1	-.00037	-.00351	.00276

Plot regression curve on present graph

APPENDIX A10

GRAPHS of BED MATERIAL SIEVE ANALYSIS

```

0: "Tape 1:File 5: Sieve Analysis Semi-log Graph Plot Bed Material":
1: dim A$(6,10),B$(10);cfd 13:csiz 1:csv:fd 1:"2.75""2.85""1.87""2.36""3.54""3.54""3.54""3.54""3.54""3.54"
2: " #6""16""30""40""60""100""200""425""670""1180""2500"
3: for G=1 to 30:G:next G
4: ent "Run Number",B$:prt " "
5: for H=1 to 6:prt A$(H):next H:spc:prt "Sieve mass"
6: ent r1:prt r1:r1=534.13
7: ent r2:prt r2:r2=537.7
8: ent r3:prt r3:r3=457.9
9: ent r4:prt r4:r4=445.23
10: ent r5:prt r5:r5=370.23
11: ent r6:prt r6:r6=356.33
12: prt "Ash Mass":for J=1 to 6:prt r1:M:next J:prt "Total":M:spc
13: for J=1 to 6:(100/J/M)*(10+J)+(17+J)+(20+J):next J:prt "%1"
14: for K=1 to 2:for N=1 to 6:prt r1:tot:next H:spc:prt "20":next
15: prt "*****":spc:pen# 1:slt 2,4,0,100:fd 0
16: sas 0,1,2,4:vas 2,10,0,100,1
17: .0163X:100:LF
18: plt 2.75, 10,0:csiz 2,2,1,0:lbl "Screen Openings (microns)"
19: pen# 2:plt 2.85,-18,0:lbl "Tyler-Screen Mesh #":pen# 1
20: csiz 2,2,1,90:plt 1.87,35:lbl "% Oversize":csiz 1,8,1,5,1,0
21: pen# 4:plt 2.3,110,1:lbl "Bed Material Mechanical Sieve Analysis"
22: plt 3.5,105,1:lbl B$:csiz 1,7,2,1,0:fd 1
23: plt 3.4,100,1:lbl "Mesh % Oversize":95:LF
24: for R=1 to 6:plt 3.4,R,1:lbl A$(R):plt 3.5,0,1:lbl r0+200:B:3:next
25: fd 0:pen# 1:csiz:plt log(L) 3X,-6, 1:lbl L:10:1:LF
26: plt log(L):-1,-2:A+13A
27: if A=10:plt 0,2X,-1:03A:plt log(L) 3X,-6, 1:1:1:LF:imp
28: if A#10:plt 0,2,-1
29: L+P:L
30: if log(L) =4:imp -4
31: csiz 1,2,1,1,0:pen# 2:plt 2,-13:lbl A$(6)
32: plt log(250),-13:lbl A$(5)
33: plt log(850),-13:lbl A$(4)
34: plt log(1180),-13:lbl A$(3)
35: plt log(3350),-13:lbl A$(2)
36: plt log(6700),-13,1:lbl A$(1):csiz 2,2,1,0:pen
37: plt log(6700),r21,-2
38: plt log(3350),r22,-2
39: plt log(1180),r23,-2
40: plt log(850),r24,-2
41: plt log(250),r25,-2
42: plt 2,r26,-2
43: pen# :end
*24689

```

Bed Material Mechanical Sieve Analysis

DC 1-9

Mesh	% Oversize
.285"	2.2
#6	4.8
#16	44.4
#28	88.4
#60	99.5
PAN	100.0

X Oversize

100
90
80
70
60
50
40
30
20
10
0

100

1000

10000

Screen Opening (microns)

#20 #100

#200

PAN

#6 - 205"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 1-11

Mesh	% Oversize
200	2.1
#8	4.7
#18	39.1
#28	75.4
#60	98.4
PAN	100.0

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

PAN

#60

#20 #10

#20 #10

Bed Material Mechanical Sieve Analysis

DC 1-12

Mesh	X Oversize
.265"	0.7
#6	2.1
#10	42.3
#20	85.2
#60	99.4
PAN	100.0

Screen Openings (microns)

#20 #10

Tyler Screen Mesh #

#60

PAN

#6

.265"

Bed Material Mechanical Sieve Analysis

9-200

Mesh	X Over Size
.265"	7.9
#8	11.2
#10	48.5
#20	82.7
#60	98.1
PAN	100.0

Screen Opening (microns)

NOT

2
3
4

Taylor Sharon Mosh

NON

Bed Material Mechanical Sieve Analysis

DC 2-11

Mech	X Oversize
.285"	0.8
#8	7.0
#16	22.7
#20	60.6
#60	80.8
PAN	100.0

Screen Openings (microns)

#20 #100

PAN

Tyler Screen Mesh #

#8 .285"

Bed Material Mechanical Sieve Analysis

DC 3-7

Mesh	% Oversize
.25"	0.0
#8	2.2
#16	31.4
#20	62.2
#60	99.7
PAN	100.0

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 3-B

Mesh	% Oversize
.265"	2.0
#6	5.7
#16	44.1
#28	79.8
#60	99.8
PAN	100.0

Screen Opening (microns)
#20 #40

Tyler Screen Mesh #

#0 - 265"

Bed Material Mechanical Sieve Analysis

DC 3-B

Mesh	% Oversize
.285"	2.9
#6	5.7
#16	44.1
#20	79.6
#60	98.0
PAN	100.0

Screen Openings (microns)

#20 #16

#60

PAN

Tyler Screen Mesh #

#6

.285"

Bed Material Mechanical Sieve Analysis

DC 3-10

Mesh	% Oversize
265"	0.1
#8	1.5
#16	35.2
#20	75.9
#60	98.7
PAN	100.0

Screen Openings (microns)

Tyler Screen Mesh #

PAN

Bed Material Mechanical Sieve Analysis

DC 4-9

Mesh	% Oversize
.25"	1.1
#8	3.9
#16	53.3
#20	91.1
#60	98.8
PAN	100.0

Screen Opening (microns)

#20 #10 #5 - 205"

Tyler Screen Mesh #

#60

PAN

Bed Material Mechanical Sieve Analysis

DC 4-10

Mesh	% Overize
.285"	0.8
#6	2.3
#16	42.1
#20	79.9
#60	98.4
PAN	100.0

Screen Openings (microns)

#6 .25"

#20 #10

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 4-11

Mesh	% Oversize
.25"	1.4
#3	5.4
#18	51.8
#20	87.7
#60	89.8
PAN	100.0

Screen Opening (microns)

#20 #10

#60

PAN

#60

- 205"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 5-9

Mech	% Oversize
.285"	3.9
#6	6.4
#16	42.9
#20	78.1
#60	98.2
PAN	100.0

Screen Opening (microns)

#20 #16

#6

.285"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 5-10

Mesh	% Over-size
.25"	9.2
#6	4.8
#16	47.5
#20	81.7
#60	98.9
PAN	100.0

Tyler Screen Mesh #

#6 .25"

Bed Material Mechanical Sieve Analysis

DC 6-9

Mesh	% Oversize
.285"	2.3
#6	4.5
#16	45.7
#20	82.9
#60	99.5
PAN	100.0

Screen Opening (Inches)

#20 #10

Tyler Screen Mesh #

#60

PAN

#6 - 255"

10000

Bed Material Mechanical Sieve Analysis

DC 6-10

Mesh	% Oversize
.285"	0.5
#6	1.7
#16	43.8
#20	83.8
#60	89.2
PAN	100.0

Screen Opening (microns)

#60

#20 #10

#5 - 205"

Tyler Screen Mesh #

PAN

Bed Material Mechanical Sieve Analysis

DC 6-12

Mesh	% Oversize
.25"	1.0
#8	8.7
#16	88.8
#20	98.5
#60	99.6
PAN	100.0

% Oversize

100
90
80
70
60
50
40
30
20
10
0

100

100

100

Screen Opening (microns)

#20 #16

#6

.25"

PAN

#60

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 6-12

Mesh	% Oversize
.25"	1.0
#6	8.7
#10	69.8
#20	96.5
#60	99.6
PAN	100.0

1000

10000

Screen Opening (microns)

#20 #10

#60

PAN

#6 .25"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 7-6

Mesh	% Oversize
.285"	1.5
#6	3.1
#16	42.3
#20	83.4
#60	97.0
PAN	100.0

Screen Openings (microns)

#60

#20 #16

#5 .285"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

QC 7-8

Mesh	% Oversize
.25"	47.9
#6	55.2
#10	71.0
#20	88.8
#60	98.7
PAN	100.0

Screen Openings (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#6 .25"

Bed Material Mechanical Sieve Analysis

DC 7-13

Mesh	% Oversize
.285"	54.2
#8	71.0
#16	81.4
#20	88.6
#60	94.0
PAN	100.0

100

PAN

#60

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

1000

100000

.285"

Bed Material Mechanical Sieve Analysis

DC 7-14

Mesh	% Oversize
.265"	0.0
#6	3.5
#10	41.0
#20	81.2
#60	97.8
PAN	100.0

Screen Opening (microns)

#60

PAN

#20 #10

#6

.265"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 8-7

Mesh	% Oversize
#285"	0.0
#8	2.0
#16	29.6
#20	73.0
#60	94.6
-PAN	100.0

100

90

80

70

60

50

40

30

20

10

0

X Oversize

100

1000

10000

Screen Opening (microns)

#20 #10

#6

- 205"

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 8-8

Mesh	% Oversize
.285"	2.9
#8	10.5
#10	48.8
#20	70.9
#60	88.9
.PAN	100.0

Screen Openings (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#6 .285"

Bed Material Mechanical Sieve Analysis

DC, B-9

Mesh	% Oversize
.265"	16.3
#6	23.4
#16	42.5
#20	67.3
#60	83.6
PAN	100.0

Tyler Screen Mesh #

.205"

#6

Bed Material Mechanical Sieve Analysis

DC B-10

Mesh	% Oversize
.285"	23.3
#8	33.8
#16	55.8
#20	78.4
#60	88.8
PAN	100.0

1000

100

10000

Screen Openings (microns)

#20 #16

#60

PAN

#8

.285"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 9-12

Mesh	% Oversize
.25"	1.0
#8	3.1
#16	13.5
#20	65.7
#60	98.4
PAN	100.0

Bed Material Mechanical Sieve Analysis

DC 9-13

Mesh	% Oversize
#205"	0.0
#8	3.3
#10	30.4
#20	73.0
#60	92.2
PAN	100.0

Screen Opening (microns)

#20 #10

#8

#205"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 9-14

Mesh	% Over-size
.285"	28.4
#6	38.6
#18	62.4
#20	86.2
#60	97.5
PAN	100.0

Screen Opening (microns)

#6 .285"

#20 #18

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 9-17

1000
Screen Openings (microns)
#20 #10
Tyler Screen Mesh #
#6 .205"

PAN

Bed Material Mechanical Sieve Analysis

DC 9-17.1

Mesh	% Oversize
.285"	73.4
#6	84.1
#16	90.5
#20	93.5
#60	97.2
PAN	100.0

100

90

80

70

60

50

40

30

20

10

0

% Oversize

100

PAN

#60

Screen Openings (microns)

#20 #10

Tyler Screen Mesh #

#6

.205"

10000

Bed Material Mechanical Sieve Analysis

DC 10-7

Mesh	% Over Size
#205"	1.0
#6	3.6
#16	35.0
#20	75.4
#60	98.7
PAN	100.0

Screen Openings (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#0 .205"

Bed Material Mechanical Sieve Analysis

DC 10-B

Mesh	% Oversize
.285"	0.9
#6	2.6
#18	33.6
#20	73.0
#60	87.3
PAN	100.0

Screen Opening (microns)

#20 #18

Tyler Screen Mesh #

#60

PAN

1000

10000

#6

.285"

Bed Material Mechanical Sieve Analysis

DC 10-9

Mesh	% Oversize
.25"	8.8
#8	3.4
#16	33.2
#20	66.6
#60	92.4
PAN	100.0

100

90

80

70

60

50

40

30

20

10

0

% Oversize

100

1000

10000

Screen Openings (microns)

#20 #10

#6

.25"

#60

PAN

Tyler Screen Mesh #

Bad Material Mechanical Sieve Analysis

DC 10-10

Mesh	X Overize
.285"	28.2
#8	39.5
#16	59.0
#20	79.7
#60	98.5
PAN	100.0

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

#60

PAN

#6

.285"

Bed Material Mechanical Sieve Analysis

DC 10-11

Mesh	X Overize
.25"	41.6
#6	54.1
#16	70.7
#20	85.4
#60	91.2
PAN	100.0

10000

Screen Opening (microns)

#20 #10

#6 .25"

Tyler Screen Mesh #

#60

PAN

Bed Material Mechanical Sieve Analysis

DC 10-12

Mesh	% Oversize
.265"	20.0
#8	31.3
#16	53.7
#20	76.1
#60	88.2
PAN	100.0

Screen Openings (microns)

#20 #10 #8 .265"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 11-9

Mesh: X Oversize

.265" 0.0

#6 1.0

#16 40.3

#20 82.4

#60 98.1

PAN 100.0

Screen Opening (microns)

#20 #16

#60

PAN

#6 .265"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 12-7

Bed Material, Mechanical Sieve Analysis

DC 14-9

Mesh	% Oversize
.265"	6.3
#8	10.5
#16	40.3
#20	83.2
#60	96.6
PAN	100.0

1000

1000

100

Screen Openings (microns)

#20 #10

#8 .265"

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 14-10

1000

Screen Opening (microns)

#20

#10

Tyler Screen Mesh #

#60

PAN

1000

100

X Overize

Bed Material Mechanical Sieve Analysis

DC 14-11

Mesh	X Oversize
.265"	1.1
#6	5.8
#16	43.7
#20	85.5
#60	98.1
PAN	100.0

Screen Opening (microns)

#20 #10

#6

.265"

Tyler Screen Mesh #

PAN

100

1000

10000

Bed Material Mechanical Sieve Analysis

DC 15-9

Mesh	% Oversize
.285"	10.5
#8	13.4
#16	46.8
#20	79.8
#60	98.1
PAN	100.0

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

#100

PAN

1000

10000

#20 #10

-205"

Bed Material Mechanical Sieve Analysis

DC 15-11

Mesh	% Oversize
.25"	1.6
#6	4.7
#16	45.8
#28	82.8
#60	98.8
PAN	100.0

Bed Material Mechanical Sieve Analysis

DC 16-7

Mesh	% Oversize
.25"	0.1
#8	0.7
#16	30.4
#20	85.3
#60	98.8
PAN	100.0

1000

Screen Opening (microns)

#20 #16

#8

.25"

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 16-B

Mech	X Oversize
#20	6.4
#16	13.5
#28	47.5
#60	82.0
PAN	97.6
	100.0

Screen Openings (microns)

Tyler Screen Mesh #

#20

PAN

#20 - 250"

10000

Bed Material Mechanical Sieve Analysis

QC 16-10

Mesh	X Oversize
.25"	0.3
#6	3.1
#16	50.1
#20	88.4
#60	98.3
PAN	100.0

Screen Opening (microns)

#6 .25"

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 17-7

Mesh	X. Oversize
.265"	0.2
#6	1.4
#16	98.2
#20	78.9
#60	98.5
PAN	100.0

Screen Opening (microns)

#20 #16

Tyler Screen Mesh' #

#60

PAN

#6 - .265"

1000

10000

Bed Material Mechanical Sieve Analysis

DC 17-8

10000

Screen Openings (microns)

205"

#8

Tyler Screen Mesh #

#60

PAN

100

Bed Material Mechanical Sieve Analysis

DC 17-9

Bed Material Mechanical Sieve Analysis

DC 18-B

Mesh	% Oversize
265"	0.0
#6	0.8
#16	28.9
#28	79.5
#60	99.1
PAN	100.0

Screen Openings (microns)

#6 - 265"

#20 #10

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 18-10

Mesh	% Oversize
.25"	4.2
#6	6.6
#16	42.8
#28	81.8
#60	98.2
PAN	100.0

100 1000 10000

Screen Opening (microns)

PAN #60 #28 #16 #6 .25"

Tyler Screen, Mesh #

Bed Material Mechanical Sieve Analysis

DC 20-7

Mesh	% Oversize
.265"	0.2
#8	1.2
#16	38.3
#20	79.3
#60	98.7
PAN	100.0

Screen Openings (microns)

#20 #10
Tyler Screen Mesh #

PAN

Bed Material Mechanical Sieve Analysis

DC 20-10

10000

Screen Opening (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#6

.285"

Bed Material Mechanical Sieve Analysis

DC 20-9

Mesh	X Overize
.285"	0.2
#6	4.5
#10	49.4
#20	83.4
#60	99.1
PAN	100.0

Screen Opening (microns)

#20 #10

#6

.285"

Tyler Screen Mesh #

#60

PAN

1000

1000

100

Bed Material Mechanical Sieve Analysis

DC 21-7

Mesh	X Oversize
.265"	0.9
#6	3.2
#16	48.9
#20	79.4
#60	98.7
PAN	100.0

X Oversize

100

1000

10000

Screen Opening (microns)

#60

#20 #16

#6 .265"

PAN

Tyler Screen Mesh, #

Bed Material Mechanical Sieve Analysis

DC 21-9

Mesh	X Oversize
.285"	2.2
#8	4.1
#16	38.5
#20	74.8
#60	97.5
PAN	100.0

Screen Openings (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#20 - 205"

1000

10000

Bad Material Mechanical Sieve Analysis

DC 22-8

Mesh	% Oversize
.265"	0.3
#4	1.3
#10	42.6
#20	81.9
#60	98.3
PAN	100.0

Screen Openings (microns)

Tyler Screen Mesh #

PAN

#60

#20 #10

#6

.265"

Bed Material Mechanical Sieve Analysis

DC 22-9

Mesh	% Over-size
.25"	12.8
#6	15.8
#16	42.2
#20	72.8
#60	96.2
PAN	100.0

Screen Openings (microns)
#20 850
#60 250
#100 150
#200 75
#400 37.5
#600 25
#800 18.75
#1000 15
#1250 12.5
#1500 10
#1750 8.5
#2000 7.5
#2500 6
#3000 5
#3500 4.25
#4000 3.75
#4500 3.35
#5000 3
#5600 2.6
#6300 2.2
#7000 1.9
#8000 1.6
#9000 1.4
#10000 1.25
#11200 1.1
#12500 1
#14000 .85
#16000 .75
#18000 .65
#20000 .6
#22400 .53
#25000 .475
#28000 .425
#31500 .375
#35500 .335
#40000 .3
#45000 .265
#50000 .235
#56000 .21
#63000 .1875
#70000 .1675
#80000 .1475
#90000 .1275
#100000 .1175
#112000 .1075
#125000 .1
#140000 .0875
#160000 .075
#180000 .065
#200000 .0575
#224000 .05
#250000 .045
#280000 .04
#315000 .035
#355000 .03
#400000 .0275
#450000 .025
#500000 .0225
#560000 .02
#630000 .0175
#700000 .015
#800000 .0125
#900000 .011
#1000000 .01
#1120000 .009
#1250000 .008
#1400000 .007
#1600000 .006
#1800000 .005
#2000000 .0045
#2240000 .004
#2500000 .0035
#2800000 .003
#3150000 .00275
#3550000 .0025
#4000000 .00225
#4500000 .002
#5000000 .00175
#5600000 .0015
#6300000 .00125
#7000000 .0011
#8000000 .0009
#9000000 .0008
#10000000 .0007
#11200000 .0006
#12500000 .0005
#14000000 .00045
#16000000 .0004
#18000000 .00035
#20000000 .0003
#22400000 .000275
#25000000 .00025
#28000000 .000225
#31500000 .0002
#35500000 .000175
#40000000 .00015
#45000000 .000125
#50000000 .00011
#56000000 .0001
#63000000 .00009
#70000000 .00008
#80000000 .00007
#90000000 .00006
#100000000 .00005
#112000000 .000045
#125000000 .00004
#140000000 .000035
#160000000 .00003
#180000000 .0000275
#200000000 .000025
#224000000 .0000225
#250000000 .00002
#280000000 .0000175
#315000000 .000015
#355000000 .0000125
#400000000 .000011
#450000000 .00001
#500000000 .000009
#560000000 .000008
#630000000 .000007
#700000000 .000006
#800000000 .000005
#900000000 .0000045
#1000000000 .000004
#1120000000 .0000035
#1250000000 .000003
#1400000000 .00000275
#1600000000 .0000025
#1800000000 .00000225
#2000000000 .000002
#2240000000 .00000175
#2500000000 .0000015
#2800000000 .00000125
#3150000000 .0000011
#3550000000 .000001
#4000000000 .0000009
#4500000000 .0000008
#5000000000 .0000007
#5600000000 .0000006
#6300000000 .0000005
#7000000000 .00000045
#8000000000 .0000004
#9000000000 .00000035
#10000000000 .0000003
#11200000000 .000000275
#12500000000 .00000025
#14000000000 .000000225
#16000000000 .0000002
#18000000000 .000000175
#20000000000 .00000015
#22400000000 .000000125
#25000000000 .00000011
#28000000000 .0000001
#31500000000 .00000009
#35500000000 .00000008
#40000000000 .00000007
#45000000000 .00000006
#50000000000 .00000005
#56000000000 .000000045
#63000000000 .00000004
#70000000000 .000000035
#80000000000 .00000003
#90000000000 .0000000275
#100000000000 .000000025
#112000000000 .0000000225
#125000000000 .00000002
#140000000000 .0000000175
#160000000000 .000000015
#180000000000 .0000000125
#200000000000 .000000011
#224000000000 .00000001
#250000000000 .000000009
#280000000000 .000000008
#315000000000 .000000007
#355000000000 .000000006
#400000000000 .000000005
#450000000000 .0000000045
#500000000000 .000000004
#560000000000 .0000000035
#630000000000 .000000003
#700000000000 .00000000275
#800000000000 .0000000025
#900000000000 .00000000225
#1000000000000 .000000002
#1120000000000 .00000000175
#1250000000000 .0000000015
#1400000000000 .00000000125
#1600000000000 .0000000011
#1800000000000 .000000001
#2000000000000 .0000000009
#2240000000000 .0000000008
#2500000000000 .0000000007
#2800000000000 .0000000006
#3150000000000 .0000000005
#3550000000000 .00000000045
#4000000000000 .0000000004
#4500000000000 .00000000035
#5000000000000 .0000000003
#5600000000000 .000000000275
#6300000000000 .00000000025
#7000000000000 .000000000225
#8000000000000 .0000000002
#9000000000000 .000000000175
#10000000000000 .00000000015
#11200000000000 .000000000125
#12500000000000 .00000000011
#14000000000000 .0000000001
#16000000000000 .00000000009
#18000000000000 .00000000008
#20000000000000 .00000000007
#22400000000000 .00000000006
#25000000000000 .00000000005
#28000000000000 .000000000045
#31500000000000 .00000000004
#35500000000000 .000000000035
#40000000000000 .00000000003
#45000000000000 .0000000000275
#50000000000000 .000000000025
#56000000000000 .0000000000225
#63000000000000 .00000000002
#70000000000000 .0000000000175
#80000000000000 .000000000015
#90000000000000 .0000000000125
#100000000000000 .000000000011
#112000000000000 .00000000001
#125000000000000 .000000000009
#140000000000000 .000000000008
#160000000000000 .000000000007
#180000000000000 .000000000006
#200000000000000 .000000000005
#224000000000000 .0000000000045
#250000000000000 .000000000004
#280000000000000 .0000000000035
#315000000000000 .000000000003
#355000000000000 .00000000000275
#400000000000000 .0000000000025
#450000000000000 .00000000000225
#500000000000000 .000000000002
#560000000000000 .00000000000175
#630000000000000 .0000000000015
#700000000000000 .00000000000125
#800000000000000 .0000000000011
#900000000000000 .000000000001
#1000000000000000 .0000000000009
#1120000000000000 .0000000000008
#1250000000000000 .0000000000007
#1400000000000000 .0000000000006
#1600000000000000 .0000000000005
#1800000000000000 .00000000000045
#2000000000000000 .0000000000004
#2240000000000000 .00000000000035
#2500000000000000 .0000000000003
#2800000000000000 .000000000000275
#3150000000000000 .00000000000025
#3550000000000000 .000000000000225
#4000000000000000 .0000000000002
#4500000000000000 .000000000000175
#5000000000000000 .00000000000015
#5600000000000000 .000000000000125
#6300000000000000 .00000000000011
#7000000000000000 .0000000000001
#8000000000000000 .00000000000009
#9000000000000000 .00000000000008
#10000000000000000 .00000000000007
#11200000000000000 .00000000000006
#12500000000000000 .00000000000005
#14000000000000000 .000000000000045
#16000000000000000 .00000000000004
#18000000000000000 .000000000000035
#20000000000000000 .00000000000003
#22400000000000000 .0000000000000275
#25000000000000000 .000000000000025
#28000000000000000 .0000000000000225
#31500000000000000 .00000000000002
#35500000000000000 .0000000000000175
#40000000000000000 .000000000000015
#45000000000000000 .0000000000000125
#50000000000000000 .000000000000011
#56000000000000000 .00000000000001
#63000000000000000 .000000000000009
#70000000000000000 .000000000000008
#80000000000000000 .000000000000007
#90000000000000000 .000000000000006
#100000000000000000 .000000000000005
#112000000000000000 .0000000000000045
#125000000000000000 .000000000000004
#140000000000000000 .0000000000000035
#160000000000000000 .000000000000003
#180000000000000000 .00000000000000275
#200000000000000000 .0000000000000025
#224000000000000000 .00000000000000225
#250000000000000000 .000000000000002
#280000000000000000 .00000000000000175
#315000000000000000 .0000000000000015
#355000000000000000 .00000000000000125
#400000000000000000 .0000000000000011
#450000000000000000 .000000000000001
#500000000000000000 .0000000000000009
#560000000000000000 .0000000000000008
#630000000000000000 .0000000000000007
#700000000000000000 .0000000000000006
#800000000000000000 .0000000000000005
#900000000000000000 .00000000000000045
#1000000000000000000 .0000000000000004
#1120000000000000000 .00000000000000035
#1250000000000000000 .0000000000000003
#1400000000000000000 .000000000000000275
#1600000000000000000 .00000000000000025
#1800000000000000000 .000000000000000225
#2000000000000000000 .0000000000000002
#2240000000000000000 .000000000000000175
#2500000000000000000 .00000000000000015
#2800000000000000000 .000000000000000125
#3150000000000000000 .00000000000000011
#3550000000000000000 .0000000000000001
#4000000000000000000 .00000000000000009
#4500000000000000000 .00000000000000008
#5000000000000000000 .00000000000000007
#5600000000000000000 .00000000000000006
#6300000000000000000 .00000000000000005
#7000000000000000000 .000000000000000045
#8000000000000000000 .00000000000000004
#9000000000000000000 .000000000000000035
#10000000000000000000 .00000000000000003
#11200000000000000000 .0000000000000000275
#12500000000000000000 .000000000000000025
#14000000000000000000 .0000000000000000225
#16000000000000000000 .00000000000000002
#18000000000000000000 .0000000000000000175
#20000000000000000000 .000000000000000015
#22400000000000000000 .0000000000000000125
#25000000000000000000 .000000000000000011
#28000000000000000000 .00000000000000001
#31500000000000000000 .000000000000000009
#35500000000000000000 .000000000000000008
#40000000000000000000 .000000000000000007
#45000000000000000000 .000000000000000006
#50000000000000000000 .000000000000000005
#56000000000000000000 .0000000000000000045
#63000000000000000000 .000000000000000004
#70000000000000000000 .0000000000000000035
#80000000000000000000 .000000000000000003
#90000000000000000000 .00000000000000000275
#100000000000000000000 .0000000000000000025
#112000000000000000000 .00000000000000000225
#125000000000000000000 .000000000000000002
#140000000000000000000 .00000000000000000175
#160000000000000000000 .0000000000000000015
#180000000000000000000 .00000000000000000125
#200000000000000000000 .0000000000000000011
#224000000000000000000 .000000000000000001
#250000000000000000000 .0000000000000000009
#280000000000000000000 .0000000000000000008
#315000000000000000000 .0000000000000000007
#355000000000000000000 .0000000000000000006
#400000000000000000000 .0000000000000000005
#450000000000000000000 .00000000000000000045
#500000000000000000000 .0000000000000000004
#560000000000000000000 .00000000000000000035
#630000000000000000000 .0000000000000000003
#700000000000000000000 .000000000000000000275
#800000000000000000000 .00000000000000000025
#900000000000000000000 .000000000000000000225
#1000000000000000000000 .0000000000000000002
#1120000000000000000000 .000000000000000000175
#1250000000000000000000 .00000000000000000015
#1400000000000000000000 .000000000000000000125
#1600000000000000000000 .00000000000000000011
#1800000000000000000000 .0000000000000000001
#2000000000000000000000 .00000000000000000009
#2240000000000000000000 .00000000000000000008
#2500000000000000000000 .00000000000000000007
#2800000000000000000000 .00000000000000000006
#3150000000000000000000 .00000000000000000005
#3550000000000000000000 .000000000000000000045
#4000000000000000000000 .00000000000000000004
#4500000000000000000000 .000000000000000000035
#5000000000000000000000 .00000000000000000003
#5600000000000000000000 .0000000000000000000275
#6300000000000000000000 .000000000000000000025
#7000000000000000000000 .0000000000000000000225
#8000000000000000000000 .00000000000000000002
#9000000000000000000000 .0000000000000000000175
#10000000000000000000000 .000000000000000000015
#11200000000000000000000 .0000000000000000000125
#12500000000000000000000 .000000000000000000011
#14000000000000000000000 .00000000000000000001
#16000000000000000000000 .000000000000000000009
#18000000000000000000000 .000000000000000000008
#20000000000000000000000 .000000000000000000007
#22400000000000000000000 .000000000000000000006
#25000000000000000000000 .000000000000000000005
#28000000000000000000000 .0000000000000000000045
#31500000000000000000000 .000000000000000000004
#35500000000000000000000 .0000000000000000000035
#40000000000000000000000 .000000000000000000003
#45000000000000000000000 .00000000000000000000275
#50000000000000000000000 .0000000000000000000025
#56000000000000000000000 .00000000000000000000225
#63000000000000000000000 .000000000000000000002
#70000000000000000000000 .00000000000000000000175
#80000000000000000000000 .0000000000000000000015
#90000000000000000000000 .00000000000000000000125
#100000000000000000000000 .0000000000000000000011
#112000000000000000000000 .000000000000000000001
#125000000000000000000000 .0000000000000000000009
#140000000000000000000000 .0000000000000000000008
#160000000000000000000000 .0000000000000000000007
#1

6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

Bed Material Mechanical Sieve Analysis

DC 29-9

Mesh	% Oversize
.25"	0.1
#8	4.1
#16	45.6
#20	86.8
#60	99.4
PAN	100.0

Screen Openings (microns)

#20 #10

#5

#20

#60

PAN

Tyler Screen Mesh #4

Bed Material Mechanical Sieve Analysis

DC 23-10

Mesh	% Oversize
.285"	7.2
#6	10.3
#16	42.8
#20	77.8
#60	98.5
PAN	100.0

10000

1000

100

Sieve Opening (microns)

#20

#60

#20 #10

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 23-12

Mesh	X Oversize
.285"	1.3
#6	7.5
#16	51.6
#20	87.0
#60	98.1
PAN	100.0

Screen Opening (microns)

#60

PAN

#20

#6

.285"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 24-7

Mesh	% Oversize
.285"	0.9
#6	2.5
#10	43.6
#20	84.8
#60	98.7
PAN	100.0

Tyler Screen Mesh #

#6 - .285"

Bed Material Mechanical Sieve Analysis

DC 24-9

Mech	X Oversize
205"	0.3
#8	1.9
#16	41.1
#28	83.0
#50	99.3
PAN	100.0

10000

Screen Opening (microns)

#20

#40

#60

#80

#100

#120

#150

#200

#250

#300

Tyler Screen Mesh #

PAN

PAN

Bed Material Mechanical Sieve Analysis

DC 25-10

Mesh	% Oversize
.285"	8.6
#8	1.8
#16	35.1
#20	73.4
#60	96.1
PAN	100.0

A10-69

Bed Material Mechanical Sieve Analysis

DC 25-11. Wet

Mesh	% Oversize
265"	10.9
#6	13.1
#16	41.1
#20	72.1
#60	98.2
PAN	100.0

Screen Openings (microns)

#20 #16

#60

#6 .265"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 25-11. Dry

Mesh	% Oversize
.265"	8.1
#6	10.3
#16	37.7
#20	68.5
#60	98.6
PAN	100.0

Screen Opening (microns)
 #20 #100
 Tyler Screen Mesh #

PAN

#60

#6

.265"

Bed Material Mechanical Sieve Analysis

DC 26-10

Mesh	% Overize
.265"	0.0
#6	0.4
#16	34.6
#20	73.8
#60	95.8
PAN	100.0

1000

Screen Openings (microns)

#6 .265"

#20

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 26-11

Mesh	% Oversize
.25"	8.2
#8	8.7
#16	34.2
#20	71.4
#60	96.1
PAN	100.0

Screen Opening (microns)

#20 #16

#60

PAN

Tyler Screen Mesh #

#8

#20

Bed Material Mechanical Sieve Analysis

DC 26-12

Mech	% Overize
.285"	7.7
#6	18.4
#16	44.7
#20	76.7
#60	97.4
PAN	100.0

Screen Opening (microns)
 #20 #16
 Tyler Screen Mesh #

PAN

#60

#6 .285"

Bed Material Mechanical Sieve Analysis

DC 27-10

Mesh	% Oversize
-205"	0.1
#8	0.3
#16	30.8
#28	71.1
#60	92.3
PAN	100.0

A10-75

Bed Material Mechanical Sieve Analysis

DC 27-11. Dry

Mesh	% Oversize
.265"	0.7
#6	1.5
#16	38.1
#20	75.6
#60	99.2
PAN	100.0

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 27-11, Wet

Mesh	% Oversize
.265"	0.8
#6	1.6
#16	38.8
#20	76.3
#60	98.1
PAN	100.0

Tyler Screen Mesh #

A10-72

Bed Material Mechanical Sieve Analysis

DC 27-12

Mesh	% Oversize
.25"	8.1
#6	7.0
#16	31.2
#20	64.4
#60	93.9
PAN	100.0

Screen Openings (microns)

#60 .205"

#20 #10

#60

PAN

Tyler Screen Mesh #0

Bed Material Mechanical Sieve Analysis

DC 28-9: Wet

Mesh	% Oversize
.25"	0.2
#6	0.4
#16	35.2
#20	74.8
#60	98.4
PAN	100.0

Screen Openings (microns)

#20 #16

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 28-9. Dry

Mesh	% Oversize
265"	0.2
#6	0.4
#16	38.2
#20	76.4
#60	98.6
PAN	100.0

1000

10000

Screen/Opening (microns)

#22 #16

#6

#265

Tyler Screen Mesh #

PAN

Bed Material Mechanical Sieve Analysis

DC 28-10, Wet

Mesh	% Oversize
.265"	7.0
#6	9.4
#16	36.4
#20	67.7
#60	93.7
PAN	100.0

10000

Screen Openings (microns)

#20 #16

#6 .265"

Tyler Screen Mesh #.

PAN

#60

100

Bed Material Mechanical Sieve Analysis

DC 28-10, Dry

Mesh	% Over
.25"	5.9
#6	8.1
#16	36.6
#20	67.8
#60	98.2
PAN	100.0

% Over

Screen Openings (microns)

#6 .265"

#20 #16

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

DC 28-11

Mesh	% Over-size
.25"	8.3
#6	8.9
#10	35.7
#20	72.1
#60	97.2
PAN	100.0

Screen Opening (microns)
#20 #10
#60
PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours, July 9, +1". : 3

Screen Opening (microns)
#20 #40

Tyler Screen Mesh #

#60 - 250"

A10-84

Bed Material Mechanical Sieve Analysis

24 Hours, July 9, +1/2-1" : 6

Mesh	% Oversize
.205"	92.9
#6	85.9
#10	88.5
#20	80.7
#60	93.8
PAN	100.0

1000 10000
 Screen Openings (microns)
 #20 #10
 Tyler Screen Mesh #

#60

PAN

.205"

Bed Material Mechanical Sieve Analysis

24 Hours, July 9, +1/4-1/2 : 3

Screen Openings (microns)

#20 #10

Tyler Screen Mesh #

#60

PAN.

- 205"

Bed Material Mechanical Sieve Analysis

24 Hours. July 8. +1/4-1/2 : 6

Mesh < % Oversize

37.8

.265"

86.4

#6

88.5

#10

89.3

#20

98.1

#60

100.0

PAN

100

90

80

70

60

50

40

30

20

10

0

X Oversize

100

PAN

#60

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

1200

10000

- 205"

Bed Material Mechanical Sieve Analysis

24 Hours, July 9, +1/8-1/4 : 3

Mesh	% Oversize
.25"	0.0
#6	19.3
#16	86.3
#20	92.2
#60	97.9
PAN	100.0

Bed Material Mechanical Sieve Analysis

24 Hours, July 8, +1/8-1/4:6

Mesh	% Oversize
.285"	0.0
#6	0.3
#16	67.0
#20	66.6
#60	98.4
PAN	100.0

Screen Opening (microns)

#20 #10

Tyler Screen Mesh #

#60

PAN

.205"

Bed Material Mechanical Sieve Analysis

24 Hours. July 9, +20-1/8 : 3

Mesh	% Oversize
.285"	0.0
#6	0.0
#16	41.9
#20	79.5
#60	97.9
PAN	100.0

10000

Screen Opening (microns)

#6 .205"

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours. July 8. +20-1/8 : 6

1000 1000
 Screen Opening (microns)
 #20 #16
 #8 - .285"
 Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours, July 8, -20 mesh : 3

Mesh	% Oversize
.285"	0.0
#6	0.0
#16	0.2
#20	0.7
#60	85.3
PAN	100.0

Screen Openings (microns)

#60

#20 #16

#6

.285"

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours, July 9, -20 .6

Mesh	% Oversize
.285"	0.0
#6	0.0
#16	1.5
#20	3.0
#60	88.7
PAN	100.0

Screen Opening (microns)

#60

PAN

Tyler Screen Mesh #

#6 .285"

Bed Material Mechanical Sieve Analysis

24 Hours. July 20. -1+1/2.3

Mesh	% Oversize
.285"	79.1
#6	84.8
#16	88.2
#20	88.6
#60	93.2
PAN	100.0

100
90
80
70
60
50
40
30
20
10
0

X
O
V
E
R
S
I
Z
E

1000 10000

Screen Openings (microns).
#20 #10

PAN #60

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours. July 20. -1+1/2 : 6

Mesh	% Over-size
.25"	80.2
#8	91.0
#16	92.7
#20	93.7
#60	95.0
PAN	100.0

10000

Screen Openings (microns)

#20 #16

#60

PAN

Tyler Screen Mesh #

#6 .205"

Bed Material Mechanical Sieve Analysis

24 Hours, July 20, -1/2+1/4 : 3

Bed Material Mechanical Sieve Analysis

24 Hours, July 20, -1/2+1/4 : 6

Bed Material Mechanical Sieve Analysis

24 Hours. July 20. -1/4-1/8".3

Mesh % Oversize

.285"	0.0
#6	2.1
#10	57.3
#20	70.0
#60	98.3
PAN	100.0

1000

Screen Opening (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#0 .205"

10000

Bed Material Mechanical Sieve Analysis

24 Hours. July 20. -1/4+1/8 : 0

Bed Material Mechanical Sieve Analysis 4 ft/1000 24 Hours, July 20, -1/8+20:3

Mesh	% Oversize
.25"	0.0
#6	0.0
#16	40.0
#20	76.6
#60	97.1
PAN	100.0

Screen Opening (microns)

#6 - 250"

#60

PAN

Tyler Screen Mesh #

Bed Material Mechanical Sieve Analysis

24 Hours, July 20, -1/8+20 .6

100 200 300 400 500 600 700 800 900 1000 1250 1500 1800 2000 2500 3000 3500 4000 4500 5000 6000 7000 8000 9000 10000 12500 15000 18000

Screen Opening (microns)

100 200 300 400 500 600 700 800 900 1000 1250 1500 1800 2000 2500 3000 3500 4000 4500 5000 6000 7000 8000 9000 10000 12500 15000 18000

Tyler Screen Mesh #

#6 .205"

#20 #10

#60

PAN

Bed Material Mechanical Sieve Analysis

24 Hours, July 20, -20 mesh

Mesh	Oversize
.285"	0.0
#6	0.1
#16	1.1
#20	2.1
#60	86.4
PAN	100.0

Screen Opening (microns)

#20 #10

#60

PAN

Tyler Screen Mesh #

#6 -205"

APPENDIX A11

GRAPHS of CYCLONE ASH SIEVE ANALYSIS

A11-2

```

0: "Tape 1:File 4: Sieve Analysis Semilog Graph Plot-Cyclone Ash":
1: dim A$(6,10),B$(10);cfg 13;csiz :csv;fxd 1:" #20")A$(1)
2: " #60")A$(2);"#100")A$(3);"#200")A$(4);"#325")A$(5);" PAN")A$(6)
3: for G=1 to 30:orG:next G
4: ent "Run Number?",B$:prt "=====",B$,"=====":spc
5: for H=1 to 6:prt A$(H):next H:spc :prt "Sieve mass (g)"
6: ent r1:prt r1:r1=445.7:r1
7: ent r2:prt r2:r2=369.4:r2
8: ent r3:prt r3:r3=356.3:r3
9: ent r4:prt r4:r4=348.1:r4
10: ent r5:prt r5:r5=332.4:r5
11: ent r6:prt r6:r6=356.2:r6:spc
12: prt "Ash Mass":for I=1 to 5:prt r1:M+I*M:next I:prt "Totals:",M:spc
13: for J=1 to 6:(100rJ/M3r(10+J))r(19+J)r(20+J):next J:prt "1%"
14: for K=1 to 2:for N=1 to 6:prt rJof IN:next N:spc :pt 1-1:prt "2.0":next
15: prt " ***** ":spc :pen# 1:sc1 1,1,0,100:fxd 0
16: xax 0,1,1,3:yax 1,10,0,100,1
17: .0163X;100L3F
18: plt 1.6,-10,0:csiz 2,2,1,0:lbl "Screen Openings (microns)"
19: pen# 2:plt 1.7,-18,0:lbl "Tyler Screen Mesh #":pen# 1
20: csiz 2,2,1,90:plt .85,35:lbl "% Over size":siz 1,0,1,5,1,0
21: pen# 4:plt 1.5,110,1:lbl "Cyclone Ash Mechanical Sieve Analysis"
22: plt 2.7,105,1:lbl B$:csiz 1,7,2,1,0:fxd 1
23: plt 2.5,100,1:lbl "Mesh % Over size":95:B
24: for F=1 to 6:plt 2.5,B,1:lbl A$(F):plt .25,0,1:lbl r1of F:next F
25: fxd 0:pen# 1:csiz :plt log(L)-3X,-6,1:lbl 1:L3F:10A
26: plt log(L),-1,-2:A+10A
27: if A=10:iplt 0,2X,-1:03A:plt log(L)-3X,-6,1:lbl 1:L3F:imp
28: if A#10:iplt 0,2,-1
29: L+P:L
30: it log(L)-3:imp 4
31: csiz 1,1,1,0:pen# 2:plt 1,-13:lbl A$(6)
32: plt log(44),-13:lbl A$(5)
33: plt log(75),-13:lbl A$(4)
34: plt log(150),-13:lbl A$(3)
35: plt log(250),-13:lbl A$(2)
36: plt log(850),-13,1:lbl A$(1):csiz 2,2,1,0:pen
37: plt log(850),r21,-2
38: plt log(250),r22,-2
39: plt log(150),r23,-2
40: plt log(75),r24,-2
41: plt log(44),r25,-2
42: plt 1,r26,-2
43: pen# :end
*8947

```


Cyclone Ash Mechanical Sieve Analysis

DC 1-7

Mesh	% Oversize
#20	8.6
#60	19.0
#100	48.5
#200	58.2
#325	68.3
PAN	100.0

Screen Opening (microns)

PAN

#20

#60

#100

#200

#325

100

1000

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 2-7

Mesh	% Oversize
#20	8.3
#60	21.1
#100	42.1
#200	62.5
#325	75.6
PAN	100.0

Screen Opening (microns)

#20 #60 #100 #200 #325 PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 3-11

Mesh	% Over Size
#20	8.1
#60	13.4
#100	28.4
#200	62.9
#325	75.7
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 4-B

Mesh	% Oversize
#20	0.0
#60	11.9
#100	35.7
#200	64.7
#325	80.0
PAN	100.0

Gyalone Ash Mechanical Sieve Analysis

DC 5-8

Mesh	% Oversize
#20	0.0
#60	0.0
#100	27.1
#200	51.3
#325	64.4
PAN	100.0

Screen Opening (microns)

PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 6-8

Mech	% Oversize
#20	0.0
#60	2.0
#100	18.5
#200	43.9
#325	60.4
PAN	100.0

1000

#20

#60

#100

#200

#325

PAN

10

20

60

100

Screen Openings (microns)

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 7-5.1

Mesh	% Oversize
#20	0.1
#60	16.6
#100	31.8
#200	48.8
#325	75.1
PAN	100.0

Screen Opening (microns)

Tyler Screen Mesh #

PAN

#100

#20

Cyclone Ash Mechanical Sieve Analysis

DC 7-5.2

Mesh	% Oversize
#20	2.1
#60	16.3
#100	33.3
#200	54.1
#325	68.8
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 7-17

Mesh	% Oversize
#20	2.4
#60	20.4
#100	68.0
#200	68.5
#325	84.3
PAN	100.0

Screen Openings (microns)

#20 #60 #100 #200 #325

Tyler Screen Mesh #

PAN

Cyclone Ash Mechanical Sieve Analysis

DC 8-11

Mesh	% Oversize
#20	9.4
#60	20.4
#100	44.1
#200	70.4
#325	84.0
PAN	100.0

1000

Screen Openings (microns)

#20

#60

#100

#200

#325

PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 8-12

Mesh	% Oversize
#20	8.4
#60	18.0
#100	30.0
#200	62.1
#325	78.0
PAN	100.0

Screen Opening (microns)

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 8-4.1

Mesh	X Overize
#20	0.2
#60	14.6
#100	30.1
#200	54.8
#325	81.1
PAN	100.0

1000

Screen Opening (microns)
#200 1000
#325 1000
#100 1000
#20 1000

Tyler Screen Mesh #

PAN

Cyclone Ash Mechanical Sieve Analysis

DC 9-4.2

Mesh	% Oversize
#20	8.1
#60	17.3
#100	38.6
#200	78.9
#325	88.7
PAN	100.0

Screen Openings (microns)

#20

#60

#100

#200

#325

PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 9-10.1

Mesh	% Oversize
#20	8.1
#60	19.5
#100	42.3
#200	68.8
#325	75.7
PAN	100.0

1000

#20

#60

#100

#200

#325

PAN

Screen Openings (microns)

Taylor Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis DC 9-10.2

Mesh	X Oversize
#20	0.1
#60	14.2
#100	28.8
#200	50.5
#325	67.8
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 9-16

Mesh	% Oversize
#20	0.3
#60	12.3
#100	33.0
#200	76.4
#325	89.2
PAN	100.0

100

90

80

70

60

50

40

30

20

10

0

% Oversize

10

100

1000

Screen Opening (microns)

#325

#200

#100

#60

#20

Tyler Screen Mesh #

PAN

Cyclone Ash Mechanical Sieve Analysis

DC 10-13

Mesh	% Oversize
#20	1.3
#60	10.0
#100	53.7
#200	72.7
#325	87.0
PAN	100.0

Screen Openings (microns)

#20 #60 #100 #200 #325

Tyler Screen Mesh #

PAN

1000

#20

Cyclone Ash Mechanical Sieve Analysis

DC 11-10

Mesh	% Oversize
#20	0.0
#60	16.0
#100	50.3
#200	74.1
#325	83.0
PAN	100.0

Screen Opening (microns)

#325 #200 #100 #60 #20

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 11-12

Mesh	% Oversize
#20	8.2
#60	13.4
#100	54.1
#200	76.2
#325	84.5
PAN	100.0

Screen Opening (microns)

#20 #60 #100 #200 #325

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 12-9

Mesh	% Overize
#20	0.0
#60	5.0
#100	17.0
#200	35.3
#325	51.9
PAN	100.0

Screen Openings (microns)

#325 #200 #100 #60 #20

Tyler Screen Mesh #

100

1000

PAN

Cyclone Ash Mechanical Sieve Analysis

DC 14-7

Mesh	% Oversize
#20	8.5
#60	22.7
#100	47.4
#200	70.9
#325	88.8
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 15-7

Mesh	% Oversize
#20	0.1
#60	11.2
#100	33.7
#200	74.1
#325	85.0
PAN	100.0

100

90

80

70

60

50

40

30

20

10

100

100

Screen Opening (microns)

#325

#200

#100

#60

#20

Tyler Screen Mesh #

PAN

% Oversize

Cyclone Ash Mechanical Sieve Analysis

DC 16-12

Mesh	% Over-size
#20	8.2
#60	14.7
#100	51.3
#200	78.6
#325	85.8
PAN	100.0

Screen Openings (microns)

Tyler Screen Mesh #

#20

#60

#100

#200

#325

PAN

Cyclone Ash Mechanical Sieve Analysis

DC 17-11

Mesh	% Oversize
#20	8.8
#60	14.4
#100	40.7
#200	71.8
#325	88.8
PAN	100.0

100

Screen Opening (microns)

#200 #100 #60

Tyler Screen Mesh #

PAN

1000

#200

Cyclone Ash Mechanical Sieve Analysis

DC 18-12

Mesh	% Oversize
#20	0.3
#60	7.3
#100	24.8
#200	50.4
#325	66.8
PAN	100.0

Screen Opening (microns)

#20

#60

#100

#200

#325

#400

#500

#600

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 20-12

Mech	% Over-size
#20	0.1
#60	11.0
#100	27.2
#200	55.9
#325	72.0
PAN	100.0

100
90
80
70
60
50
40
30
20
10
0

% Over-size

100
90
80
70
60
50
40
30
20
10
0

Screen Openings (microns)

#20 #60 #100 #200 #325

Tyler Screen Mesh #

PAN

#20

#20

Cyclone Ash Mechanical Sieve Analysis

DC 21-10

Mesh	% Oversize
#20	8.1
#60	14.8
#100	32.4
#200	59.1
#325	79.3
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 21-12

Mesh	% Oversize
#20	0.2
#60	20.6
#100	44.8
#200	66.6
#325	83.5
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 22-11

Mesh	% Overize
#20	8.1
#60	15.8
#100	43.2
#200	67.8
#325	88.1
PAN	100.0

Screen Opening (microns)

Tyler Screen Mesh #

PAN

Cyclone Ash Mechanical Sieve Analysis DC 23-7

Mesh	% Oversize
#20	8.1
#60	18.7
#100	28.5
#200	48.6
#325	81.4
PAN	100.0

100
100
Screen Openings (microns)
#100
#200
#325
Tyler Screen Mesh #

1000

Cyclone Ash Mechanical Sieve Analysis

DQ 24-10

Mesh	% Over-size
#20	8.8
#60	7.2
#100	26.5
#200	47.1
#325	71.2
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 25-7

Sieve	% Oversize
#20	0.1
#60	14.5
#100	41.8
#200	68.4
#325	82.8
PAN	100.0

Sieve Opening (microns)

#20 #60 #100 #200 #325 PAN

Cyclone Ash Sieve #

Cyclone Ash Mechanical Sieve Analysis

DC 26-7

Mesh	% Over Size
#20	8.1
#60	13.3
#100	39.7
#200	62.9
#325	77.1
PAN	100.0

Screen Openings (microns)

1000 #20

100 #100

10 #200

PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

DC 27-7

Mesh	% Oversize
#20	0.2
#60	18.8
#100	41.4
#200	73.3
#325	84.2
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

DC 28-7

Mesh	% Oversize
#20	0.2
#60	26.0
#100	54.3
#200	72.0
#325	82.5
PAN	100.0

Cyclone Ash Mechanical Sieve Analysis

24 Hrs. July 9

Mesh	% Oversize
#20	0.2
#60	17.0
#100	46.2
#200	66.7
#325	79.3
PAN	100.0

1000

Screen Opening (microns)

#20

#60

#100

#200

#325

PAN

Tyler Screen Mesh #

Cyclone Ash Mechanical Sieve Analysis

24 Hrs. July 20

Mesh	% Overize
#20	0.1
#60	0.9
#100	30.8
#200	68.8
#325	77.8
PAN	100.0

Screen Openings (microns)

#20 #60 #100 #200 #325

Tyler Screen Mesh #

APPENDIX A12

DETERMINATION of FACTOR " M "

in SULPHUR RETENTION EQUATION

FACTOR M vs Ca/S RATIO (tests w/ no recycle)

FACTOR M vs Ca/S RATIO (tests w/ recycle)

FACTOR M vs Ca/S RATIO (tests w/ NO Recycle)

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
Ca/S RATIO	6	3.87833	1.35338	1.16335	29.99608
FACTOR M	6	-.31588	.00518	.07195	22.77600
CORRELATION = .52774					

PRELIMINARY ADV

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ) X ²	.02588083 .00720793			
	.2785047038		1.5440416881	(1,4)

Degree of regression (≤ 1) = 2

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	5	.025881		
REGRESSION	1	.007208	.007208	
1.5440				
X 1	1	.007208	.007208	
1.5440				
RESIDUAL	4	.018673	.004668	

VARIABLE	REGRESSION COEFFICIENTS		STANDARD ERROR REG. COEFFICIENT	T-VALUE
	STD. FORMAT	E-FORMAT		
CONSTANT	-.44246	-.442460724903E+00	.10562	-4.19
X 1	.03264	.326370584193E-01	.02627	1.24

Confidence coefficient (e.g., 90,95,99) = ?

COEFFICIENT	95 % CONFIDENCE INTERVAL	
	LOWER LIMIT	UPPER LIMIT
CONSTANT	-.44246	-.73571
X 1	.03264	.04029

Plot regression curve on present graph ?

FACTOR M vs Ca/S RATIO (tests w/ recycle)

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFF. OF VARIATION
Ca/S RATIO	6	3.66500	.52755	.72633	19.81791
FACTOR M	6	-.53813	.00950	.09747	18.11238

CORRELATION = -.42230

PRELIMINARY ANOVA

SOURCE	SS (ADDITIONAL)	F-VALUE	DF	R ² (CUMULATIVE)
TOTAL (ADJ)	.04750085			
X-1	.00847119			
	.1783375337		.8681790446	(1,4)

Degree of regression ($k-1$) = 2

ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	5	.047501		

XI. VITA

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- testing of Eastern Canadian coals in pilot
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- testing of various Eastern Canadian coals
in FBC boilers at Summerside, PEI

- redesign and modifications of FBC boilers and

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