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BUILDING CODE AND

FIRE CODE SUMMARY

FOR

FRASER SURREY DOCKS LIMITED PARTNERSHIP

COAL BARGE LOADING FACILITY

11060 ELEVATOR ROAD

SURREY, BC

Prepared for:

Fraser Surrey Docks Limited Partnership
11060 Elevator Road
Surrey, BC V3V 2R7

May 29, 2013
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INTRODUCTION

This report is intended to summarize the requirements of the National Building Code and National Fire Code, and other recognized standards in accordance with good engineering practice with regard to *the* construction of a coal barge loading facility. The project consists of constructing a coal unloading facility which unloads coal via a bottom dump from railway cars to barges via a system of conveyors.

This report contains a description of the *associated* buildings and occupancy. This report also addresses fire protection for the *rail unload facility including* conveyors, associated equipment and control rooms.

This report has been revised to address the following:

1. *Relocation and reconfiguration of the rail unloading facility (see drawing in Appendix A),*
2. *Relocation of the MCC Building and Control Room (see drawing in Appendix A),*
3. *Revisions to spatial separation requirements (see drawing in Appendix A),*
4. *Addition of a ladder in the equipment pit under rail unload shelter (see drawing in Appendix A),*
5. *Updated particle size analysis report prepared by Jenike & Johanson Science Engineering Design dated November 21, 2014 (see report in Appendix C), and*
6. *Revision to occupancy classification based on updated coal particle size information.*

This report has been revised, all changes are in italics.

The project consists of a bottom dump coal railcar unloading shelter, equipment pit and tunnel, exterior equipment and two ancillary control buildings. Plans are attached in Appendix A. The rail unload *shelter* will be classified as a Group F, Division *1 high*-hazard industrial occupancy.

This report is based on a review of plans provided by CWA Engineers Inc. and Fraser Surrey Docks. It is the responsibility of the registered professionals of this project to ensure that the fire protection and life safety requirements of the applicable Codes and Standards are incorporated into this project. References are made to:

- National Building Code 2010 (NBC)
- National Fire Code 2010 (NFC)
- Canadian Electrical Code *2012*
- National Fire Protection Association (NFPA) 120 “Fire Protection and Control in Coal Mines”, 2010 Edition
- NFPA 10 “Portable Fire Extinguishers,” 2010 Edition
- NFPA 13, “Installation of Sprinkler Systems” 2013 Edition
- *Decker Coal analysis prepared by Jenike & Johanson Science Engineering Design, dated November 21, 2014*

RAIL UNLOAD FACILITY

OCCUPANCY CLASSIFICATION

The National Building Code defines a high-hazard industrial occupancy (Group F, Division 1) as "an industrial occupancy containing sufficient quantities of highly combustible and flammable or explosive materials which, because of their inherent characteristics, constitute a special fire hazard." Therefore, with respect to processes that handle coal, areas where there is a significant risk of creating a potential dust explosion hazard should be classified as a Group F, Division 1 occupancy. It is proposed to classify the rail unload shelter as a *high*-hazard industrial occupancy (Group F, Division *1*), *based on the Jenike & Johanson Science Engineering Design Decker Coal analysis dated November 21, 2014*. A copy of the *Deck Coal analysis is attached in Appendix C. It is our understanding that this analysis was conducted on a coal sample that is representative of the coal that will typically be handled at the rail unload facility.*

The data shows that 23.7 % of the coal passed through a 0.490 mm^2 aperture (equivalent to a No. 40 sieve). This sieve size allows particles less than 420 microns to pass through. In other words, 76.3% of the coal is greater than 420 microns in size. 9.21 % of the particles passed through a 0.150 mm^2 aperture (equivalent to a No. 100 sieve), which allows particles less than 149 microns to pass through.

A paper published by the US National Institute of Occupational Safety and Health (attached in Appendix D for reference), includescoal particles plotted on a graph where the x-axis represents the particle size in microns, and the y-axis represents the minimum explosive concentration (MEC), in g/m^3 (also referred to as the Lower Explosive Limit). From this graph it can be determined that particle sizes larger than 300 microns were not in the explosive range, for the particular coal analysed. It should be noted that the properties of coal vary depending on the composition of the type of coal.

At the rail unload facility, there is no grinding of the coal, as the operation consists of transferring coal as a bulk commodity. During the unloading process coal is bottom dumped to a system of conveyors, which takes place within the rail unload shelter. *During normal operations, the process is* considered to have a low potential for creating a dust cloud, as water-spray is applied to the coal during the unloading of the coal. The water spray system is intended to reduce the potential for fine dust particles from becoming suspended in air, which could create an explosion potential.

Appendix note A-5.3.1.3.(2) of the National Fire Code references NFPA 120, "Fire Prevention and Control in Coal Mines," as an acceptable reference standard for good engineering practice. Although not specifically applicable to the rail unload facility, NFPA 120 provides guidance for the fire protection of coal conveyance and storage facilities. Reference 6.2.1.3 of NFPA 120 states that enclosed areas where the coal and coal particles are wet to prevent the particles from becoming airborne, such that a dust cloud will not form, should be classified as non-hazardous. A copy of the Reference 6.2.1.3 of NFPA 120 is attached in Appendix B.

There is a risk of explosion *or rapid oxidation* if an ignition source *is introduced into suspended combustible dust particles if the particles are within the explosive range*. The ignition source could be a spark, or high temperatures developed by malfunctioning equipment. Locations where combustible dust is not normally *suspended* in quantities sufficient to produce explosive or ignitable mixtures, but may be in suspension as a result of infrequent malfunctioning of equipment or systems will be classified as Class II, Division 2 with respect to electrical equipment. *Potential ignition* from an electrical source *should not occur* as listed electrical equipment *is required and conductors, switches etc. are required to comply with the Canadian Electrical Code for a Class II, Division 2 area*. The most probable source of ignition will be heat generated by a malfunctioning conveyor. Sensors will stop conveyors if slippage is detected.

Airborne dust with a high moisture content is difficult to ignite and more energy is required to maintain the chain reaction required for rapid oxidation and explosion. One of the conditions for a dust explosion to occur is that the dust must be in suspension. The main coal transfer points will be protected with water spray, as an additional mitigating feature to reduce the possibility of airborne dust particles. The water spray will wet the dust particles and the additional weight will cause the dust particles to fall out of suspension. In order for a dust explosion to occur, a chain reaction of ignited dust particles must take place. The water vapour, as a result of the water spray, will reduce the temperature of the unloading area. The water vapour will also reduce the temperature of *potential* hot spot ignition sources.

The water spray will reduce the likelihood of ignition by:

- Wetting the dust, and
- Cooling the environment.

There are no water spray standards or coordinated design criteria for the reduction of airborne dust. The knowledge and expertise of the engineer designing the system based on first principles is the design approach.

EQUIPMENT PIT

A portion of the coal unload facility equipment is located below grade in an equipment pit and tunnel. The purpose is to allow the coal *rail* line to roll over top to allow for *bottom dumping of* coal. The equipment pit and tunnel contain a series of conveyors, and a hopper to allow for the off loading of coal from the rail cars to the barge. The unload shelter and equipment pit are not intended to be occupied during day-to-day operations as the equipment can be monitored remotely from the MCC buildings. Access to the space is *via* ladders and will be limited to repair, maintenance and inspection of the equipment.

The equipment pit and tunnel will be protected by an automatic sprinkler system design in accordance with NFPA 120 and NFPA 13. See the sprinkler protection discussion in the Automatic Fire Suppression System section in the NFPA 120 Coal Handling section of this report for additional information.

APPROACH TO CODE COMPLIANCE

RAIL UNLOADING FACILITY

The rail unload shelter will be considered a single building within the context of the National Building Code. The rail unload shelter will be classified as a Group F, Division *1* occupancy.

Major Occupancy	-	Group F, Division *1*
Construction Article	-	*3.2.2.70 (Group F Division 1, up to 2 Storeys, Sprinklered)*
Construction	-	Combustible or Noncombustible
Building Height	-	One Storey
Approximate Building Area	-	Approximately *195* m², *2,400* m² Permitted
Sprinklered	-	Required
Fire Alarm	-	Required
Standpipe System	-	Not Required
Roof	-	Not Rated

SPATIAL SEPARATION

The Rail Unload Shelter building is a Group F, Division *1* industrial occupancy, and is sprinklered *throughout*. A limiting distance of at least 15 m, *when measured to the property line, middle of a public thoroughfare, or an imaginary line between two buildings on the same property*, in all directions is required to allow 100% unprotected openings with no additional construction requirements for spatial separation and exposure protection purposes. *Based on the plans provided, the north and south exterior walls (short ends of the building) have an exposing building face of 122 m², and a limiting distance greater than 15 m. These building faces are permitted 100% unprotected openings and are not required to be rated.*

The east and west exterior walls (long side of the building) have an exposing building face of 238 m² and a limiting distance of 15 m and 7.8 m respectively. 33 % unprotected openings are permitted and the west building face requires a minimum 1 h fire-resistance rating and noncombustible cladding. Table 1 below summarizes the spatial separation and exposure protection requirements:

Table 1

Direction	***Area Exposing Building Face***	***Limiting Distance***	***% UPO***	***Construction Requirements***
North	*122 m²*	*> 15 m*	*100*	*none*
South	*122 m²*	*> 15 m*	*100*	*none*
East	*238 m²*	*> 15 m*	*100*	*none*
West	*238 m²*	*7.8 m*	*33*	*1 h fire-resistance rating, noncombustible cladding*

SPRINKLER PROTECTION

The building *will* be sprinklered in accordance with Article *3.2.2.70., and* the sprinkler system *will* be designed and installed in accordance with NFPA 13. *F*ire department connection to the sprinkler system will be provided at the southwest corner of the building. The equipment pit and conveyor tunnel will also be provided with automatic sprinkler protection. Please refer to the automatic fire suppression system requirements contained in Coal Handling section of this report for additional information. The Rail Unload Shelter, the equipment pit and tunnel will be zoned separately *on the fire alarm system*.

STANDPIPE SYSTEM

The Rail Unload *Shelter* is less than 14 m high and will be sprinklered in accordance with NFPA 13. A standpipe system is not required or proposed, *as the hydrant system will be used by the responding fire service.*

FIRE ALARM SYSTEM

A fire alarm and detection system is required for a sprinklered building in accordance with Sentence 3.2.4.1.(1). A single stage fire alarm system is required in accordance with Sentence 3.2.4.3.(1). The fire alarm system is required to be installed in conformance with CAN/ULC-S524, "Installation of Fire Alarm Systems," and tested in conformance with CAN/ULC-S537, "Verification of Fire Alarm Systems".

Operation of any alarm initiating device in the building will cause an audible alarm to sound throughout the building. The fire alarm system is required to be designed to notify the Fire Department via an independent central station (ULC listed central station), in accordance with Articles 3.2.4.8, 3.2.4.10, and Sentence 3.2.4.10.(5).

Audible fire alarm devices are required throughout the building, so that the alarm signal is clearly audible throughout the floor area in accordance with Article 3.2.4.19. In addition, in a building where the ambient noise level is more than 87 dBA visual signal devices are required throughout the building in accordance with Sentence 3.2.4.20.(1).

The fire alarm system is required to be electrically supervised in accordance with Article 3.2.4.10., including the automatic sprinkler system. The sprinkler system is required to be electrically supervised in accordance with Sentence 3.2.4.10.(3). to indicate a supervisory trouble signal on the fire alarm system for:

- *a) Movement of a valve handle that controls the supply of water to sprinklers,*
- *b) Loss of excess water pressure required to prevent false alarms in a wet pipe system,*
- *c) Loss of air pressure in a dry pipe system, and*
- *d) A temperature approaching the freezing point in any dry pipe valve enclosure.*

The sprinkler system is also required to be electrically supervised to indicate an alarm signal on the fire alarm system upon activation of a waterflow detecting device in accordance with Sentence 3.2.4.16.(2).

Manual stations will be provided at the exit doors of the rail unload shelter *and at points where access is provided to ladders at the pit level.*

FIRE DEPARTMENT ACCESS

Fire Department access to the site is provide by Elevator Road and a private roadway system at this large, private industrial site. Buildings and facilities can be accessed from these private roadways. A private hydrant system is installed with one above ground hydrant and numerous underground hydrant connections. We have been informed by the Surrey Fire Department that an equipment box is provided at the main gate which contains the necessary components to allow the Fire Department to make use of the underground fire hydrant system. The Fire Department access will be reviewed with the City of Surrey Fire Department. *A meeting with the Surrey Fire Services has not been arranged.*

Where Fire Department access is provided by private roadways or yards, the access route *is required* conform with Article 3.2.5.6 of the NBC.

A summary of the Code requirements are as follows:

a. Have a clear width not less than 6 m (19.7 ft.),
b. Have a centre-line radius not less than 12 m (39 ft.),
c. Have an overhead clearance not less than 5 m (16.4 ft.),
d. Have a change of gradient not more than 1 in 12.5 over a minimum distance of 15 m (49 ft.),
e. Be designed to support the expected loads imposed by firefighting equipment and be surfaced with concrete, asphalt of other material designed to permit accessibility under all climatic conditions,
f. Have turnaround facilities for any dead-end portion of the access route more than 90 m (295 ft.) long, and
g. Be connected with a public thoroughfare.

EXITING & EGRESS

With regard to the rail unload shelter, egress paths are required so that the travel distance to leave the shelter does not exceed *25 m (82 ft.)*. At least two egress paths from all parts of the rail unload shelter are required.

The equipment pit is not intended to be occupied on a regular basis. However, facilities are provided to permit persons to enter and undertake maintenance. At least two egress paths from all parts of the equipment pit are required. Egress paths are required so that the travel distance to leave the equipment pit does not exceed *25 m (82 ft.)*.

As outlined in Article 3.3.1.14, stairs serving industrial occupancies are not required to meet the dimensional guard, handrail or slip-resistance requirements exit stairways provided the stairs are only intended for occasional servicing of equipment and machinery. Egress will be provided by *three* ladders. *The ladders will be located on the northeast, the southeast, and the southwest side of the equipment pit. See drawing in Appendix A for additional information.*

HEALTH REQUIREMENTS

Additional washrooms are not proposed. Toilet facilities are provided in nearby buildings.

ACCESSIBILITY

Accessibility is not proposed in this Group F, Division 1 occupancy. *As per Article 3.8.1.1. of the National Building Code, accessibility requirements do not apply to high hazard industrial occupancies.*

EMERGENCY LIGHTING & POWER

As outlined in Sentence 3.2.7.3.(1), emergency lighting is required to be provided in exits and in principle routes providing access to exits. Lighting levels of at least 10 lx at the floor or tread level is required throughout the principle routes providing access to exit.

The coal unload facility/Shed 1 is not more than two storeys in building height and has an occupant load less than 150. Exit signs are not required to be provided.

Emergency power supply *is required to be* provided for emergency systems such as emergency lighting in accordance with Article 3.2.7.4 for a period of at least 30 minutes.

VENTILATION REQUIREMENTS

As previously noted, Reference 6.2.1.3 of NFPA 120 states that enclosed areas where the coal and coal particles are wet to prevent the particles from becoming airborne, such that a dust cloud will not form, may be classified as non-hazardous. A water spray system will be provided to prevent fine dust particles from forming, and also to reduce the potential for suspended particles such that the potential for a dust explosion is minimised.

In order to maintain a level of safety that will permit service personnel to enter the space and perform their anticipated duties the equipment pit and tunnel are required to be provided with mechanical or natural ventilation in accordance with the general requirements of Part 6 of the NBC. If mechanical ventilation is provided it should be designed, installed and maintained in accordance with *the NBC, NFC, and* referenced *ASHRAE* and NFPA *standards*. Any electrical components, such as fan motors, are required to be classified as Class II, Division 2. *Ventilation requirements with respect to the potential for noxious gases is outside the scope of this report*.

NOXIOUS GAS DETECTIONS SYSTEMS

The facility is not intended for the short-term or long term storage of coal. The coal is shipped to the facility in railcars, off-loaded from the railcars via the conveyor system onto a barge. During the loading/unloading process it may be possible for a build-up of methane gas and carbon monoxide. This is normally controlled through adequate venting during transportation (i.e. open top coal car).

The need for both methane and carbon monoxide detection should be reviewed where operations require personnel to work at or near points where coal could accumulate such as, transfer points and around or under equipment. This is outside the scope of this report.

ONE STOREY MCC *BUILDING*

There will be one dedicated main MCC building located to the south of the existing Shed One building*, and to the west of the proposed rail unload shelter*. The building area will be *29.7 m² (320 sq. ft.)*. As a result, the MCC buildings may be constructed in conformance with *and is required to comply* with Part 9 of the NBC.

Based on the following characteristics, the corresponding requirements will apply:

Major Occupancy	-	MCC - Group F, Division 2
Construction Type	-	Noncombustible
Building Height	-	One Storey
Building Area	-	*29.7 m² (320 sq. ft.).*
Sprinkler System	-	No
Fire Alarm System	-	Not Required
Standpipe System	-	Not Required

SPATIAL SEPARATION

In order to allow 100% unprotected openings and no additional construction requirements based on spatial separation and exposure protection, the limiting distances required are as follows:

Building Exterior Wall Side: *35* m²	-	*11* m Limiting Distance Required
Building Exterior Wall End: *7.1* m²	-	6 m Limiting Distance Required

Limiting distance is measured to an imaginary line between two building faces for buildings on the same property. *These limiting distances are met, to allow 100% unprotected openings.*

EMERGENCY LIGHTING & POWER

As outlined in Sentence 3.2.7.3.(1), emergency lighting is required to be provided in exits and in principle routes providing access to exits. Lighting levels of at least 10 lx at the floor or tread level is required to be throughout the principle routes providing access to exit.

The MCC Building is not more than two storeys in building height and has an occupant load less than 150. Exit signs are not required to be provided.

Emergency power supply will be provided for emergency systems such as emergency lighting in accordance with Article 3.2.7.4 for a period of at least 30 minutes.

EXITING & EGRESS

Two means of egress are provided. The maximum travel distance permitted is 30 m where two exits/means of egress are provided, this requirement is met.

***ONE STOREY* CONTROL ROOM**

There will be one control room building *also located to the south of the existing Shed One building, and to the west of the proposed rail unload shelter*. The building area will be *14.8 m² (160 sq. ft.)* as a result, the control room building may be constructed in conformance with *and is required to comply with* Part 9 of the NBC.

Based on the following characteristics, the corresponding requirements will apply:

Major Occupancy	-	Control Room - Group F, Division 2
Construction Type	-	Noncombustible
Building Height	-	*One Storey*
Building Area	-	*14.8 m² (160 sq. ft.)*
Sprinkler System	-	No
Fire Alarm System	-	*Not Required*
Standpipe System	-	Not Required

SPATIAL SEPARATION

In order to allow 100% unprotected openings and no additional construction requirements based on spatial separation and exposure protection, the limiting distances are as follows:

Building Exterior Wall Side: *17.7* m²	-	*8* m Limiting Distance Required
Building Exterior Wall End: *7.1* m²	-	6 m Limiting Distance Required

Limiting distance is measured to an imaginary line between two building faces or property lines for buildings on the same property. *These limiting distances are met to permit 100% unprotected openings.*

EMERGENCY LIGHTING & POWER

As outlined in Sentence 3.2.7.3.(1), emergency lighting is required to be provided in exits and in principle routes providing access to exits. Lighting levels of at least 10 lx at the floor or tread level is required to be throughout the principle routes providing access to exit.

The MCC Control Building is not more than two storeys in building height and has an occupant load less than 150. Exit signs are not required to be provided.

Emergency power supply will be provided for emergency systems such as emergency lighting in accordance with Article 3.2.7.4 for a period of at least 30 minutes.

EXITING & EGRESS

Two means of egress are provided. The maximum travel distance permitted is 30 m where two exits/means of egress are provided. This requirement is met.

FIRE ALARM SYSTEM

Although not required by the NBC or the NFC, in accordance with good engineering practice as outlined in NFPA 120, a smoke detection system *will be provided in* the loadout control room. Please refer to the "Fire Detection and Prevention" section for Coal Handling for a discussion of the smoke detection system.

NATIONAL FIRE CODE 2010

COMBUSTIBLE DUST

Section 5.3 of the National Fire Code provides the following requirements for occupancies where combustible dust is present. The following references are to the NFC.

Dust Removal - The buildings and machinery are to be kept clear of combustible dust in accordance with Article 5.3.1.2. Cleaning equipment is required to:

a) Be made of materials that will not create electrostatic charges or sparks,
b) Is electronically conductive and bonded to ground, and
c) Remove dust by vacuum.

Cleaning equipment is required to conform to the Canadian Electrical Code.

Where it is not possible to use a vacuum, compressed air is permitted if:

a) All sources of ignition are eliminated,
b) All machinery and equipment is de-energized unless suitable for use in Class II, Division 2 atmospheres.

Bonding and Grounding - Equipment in contact with coal dust is required to be electronically bonded and grounded. Similarly, equipment subject to static electricity build-up is required to be bonded and grounded.

Ignition Sources - An activity that produces sparks, heat or flames will not be permitted unless used in a controlled manner which does not create a hazard. Smoking will not be permitted.

CONSTRUCTION FIRE SAFETY

Section 5.6 of the *NFC* contains the requirements for construction fire safety. A construction fire safety plan is required prior to construction commencing on the site.

COAL HANDLING

NFPA 120

NFPA 120, "Standard for Fire Prevention in Coal Mines" is referenced by the National *Fire* Code 2010 and provides fire protection requirements for coal mines. Although not specifically applicable to the rail unload facility, NFPA 120 provides guidance *on the basis of good engineering practice* for the fire protection of coal conveyance and storage. Chapter 9 of NFPA 120 refers to coal conveyance and storage, while Chapter 10 of NFPA 120 refers to truck, rail and barge loadouts. Chapter 9 and Chapter 10 of NFPA 120 have been referenced as a guide for the fire protection of the *conveyor systems, equipment pit and* tunnel.

Conveyors - The following requirements are with regard to Reference 9.1 regarding fire protection of conveyors. Belt alignment limit switches are required to be provided on conveyors to shut down belts that are tracking improperly. Slip switches are required to be provided to detect slippage or a jammed belt and be interlocked to shut off driving power when the belt stops or slows downs by more than 20% of its normal speed. Power shut off is required to be provided on contributing conveyors to prevent any operating conveyor from discharging material to a stopped downstream conveyor. Hydraulic systems, if provided, are required to use only listed fire retardant hydraulic fluids or be protected by an automatic fire protection system.

Conveyor alarms are required to annunciate in the operator control room. All material used in the construction of conveyor supports and guards are required to be of noncombustible material. Conveyor construction is required to be designed to prevent coal accumulations. The possibility of static electrical discharge should be investigated and protection provided where required.

Underground Conveyor Portion - There will be a conveyor which runs underground for approximately 40 m (130 ft.). The conveyor belt is required to be of a flame resistant material. The conveyor belt is required to use a structure without a deck between the upper and lower belt flights.

Manual Extinguishing - Subsection 9.4.7 of NFPA 120 requires a means of manual extinguishing be provided for the entire length of the underground belt conveyor portion of the equipment pit. Due to the risk associated with manual firefighting in a confined area such as the conveyor tunnel it is proposed that an automatic sprinkler system be provided in the tunnel and adjacent equipment pit in lieu of providing manual extinguishing in the tunnel. See automatic fire suppression system discussion *below* for information on design requirements. The fire safety plan should address a potential incident in the underground portion of the conveyor.

Automatic Fire Suppression System - Both the equipment pit, and tunnel house, conveyor belts, drives and other associated equipment will be protected with an automatic dry pipe sprinkler system designed to the general requirements of 4.3.3.3 and 9.4.6 of NFPA 120, and installed to the general requirements of NFPA 13 is proposed for these areas. Site conditions will be addressed in the design of the system. The sprinkler engineer of record will be responsible for the design relative to NFPA 13 and other relevant standards, such as NFPA 120. A summary of the sprinkler system design requirements based on NFPA 120 are as follows:

Belt Drive and Conveyor Belt Design

Design Density	10.2 L/min/m² (0.25 USgpm/sq. ft.)
Sprinkler Spacing at the belt drive	2.4 m (8 ft.) on a Branch Line.
Sprinkler Type	Standard orifice upright.
Alarm and Shutdown	The system is required to be interlocked to shutdown the conveyor and provide an audible and visual alarm.
Sprinkler Operating Temperature	65.6°C (150°F) to 148.9°C (300°F)
Protections	Sprinklers are required to be kept free of materials that can block the discharge or insulate the fusible link.
Water Demand	The water supply is required to be capable of supplying a constant flow of water with all heads functioning for a period of 10 minutes.

Equipment Pit and Tunnel Design

Design Density	10.2 L/min/m² (0.25 USgpm/sq. ft.)
Sprinkler Spacing at the belt drive	Not to exceed 30.5 m^2 (100 sq. ft.) per sprinkler
Sprinkler Type	Standard orifice upright.
Alarm and Shutdown	The system is required to be interlocked to shutdown the conveyor and provide an audible and visual alarm.
Sprinkler Operating Temperature	65.6°C (150°F) to 148.9°C (300°F)
Protections	Sprinklers are required to be kept free of materials that can block the discharge or insulate the fusible link.
Water Demand	NFPA 13

Hydraulic Equipment - Hydraulic equipment is required to have the following alarms interlocked to shut down the equipment:

1. Low oil pressure.
2. High oil temperature.
3. Low oil level.

If the capacity of a hydraulic pump exceeds 189.3 ℓ, an automatic fire suppression system is required to be installed. The automatic fire suppression system should be actuated by a heat detector. The automatic fire suppression system should be interlocked to shut off power to the unit of a listed fire resistant fluid is *utilized* automatic fire suppression system *is not required*.

Control Room - The following references are to Section 10.4. Smoke detectors are required to be installed in a loadout control room. The smoke detector system is required to actuate an audible and visual alarm. For the Loadout Control Room, external horn and strobes interconnected with internal smoke detectors on individual sounder basis will be provided to meet the requirements for an audible and visual alarm. Strobes will be located in each compartment and a horn and strobe will be located on the exterior of the structure adjacent to the entry door. For infrequently occupied or remote locations, the system *is required to* send an alarm to a constantly attended location.

Fire Extinguishers - The following references are to Section 10.5. The fire extinguishers are required to be provided in accordance with NFPA 10 as follows:

- Class A
  - Maximum travel to extinguisher, 23 m (75 ft.)
  - Minimum rating 2A
    Maximum floor area per unit of A rating, 139 m² (1,500 sq. ft.)
    Maximum area per extinguisher, 1,045 m² (11,250 sq. ft.)
- Class BC
  - 40 BC extinguisher within 9 m (30 ft.)
  - 80 BC extinguisher within 15 m (50 ft.)

Emergency Plan - A part of the emergency response plan should include firefighting procedures during a flood.

ELECTRICAL EQUIPMENT

Electrical Classification - *As per the Canadian Electrical Code, a* Class II location is one which is hazardous because of the presence of combustible dust. A Division 2 location consists of a Class II location in which combustible dust may be in suspension in the air as a result of malfunctioning or handling or processing equipment, but such dust would be insufficient to interfere with the normal operation of electrical or other equipment and insufficient to produce explosive or ignitable mixtures except for short periods of time; or where combustible dust accumulations may be sufficient to interfere with the safe dissipation of heat from electrical equipment, or may be ignitable by abnormal operation or failure of electrical equipment.

Explosion Hazard - Based on the information provided in Appendix C, analysis of the coal product indicates that *approximately 24%* of the coal handled *may be of* a particle size *that constitutes a combustible dust*. Wetted coal dust is not considered ignitable. In order for an explosion to occur, a significant amount of coal dust is required to be suspended in the air. This is an unlikely condition which results in the Division 2 classification. The Division 2 classification is appropriate for a condition that would result from an equipment malfunction. However, if coal dust were to be suspended in the air, it is possible for an explosion to occur. Therefore, the hazardous electrical classification is applied. The sub-bituminous coal at this project has a minimum ignition temperature of 455°C to 475°C. These temperatures are achievable either by overheating or by friction.

Any enclosed areas including the coal dump area in the rail unload shelter are classified as Class II Division 2 as a result of the possible accumulation of coal dust.

An electrical classification is not provided for the hopper (Transfer Point 1) as a water spray system is provided at this location. Also, the top of the hopper is open. Electrical equipment is located outside and away from the hopper.

In areas where electrical equipment is located outdoors and in the open, there is little possibility of accumulation of coal dust and unclassified electrical equipment is permitted.

SUMMARY

This report has summarized the approach to National Building Code and National Fire Code compliance for this project which involves constructing a rail unload/barge loading facility for transportation of coal.

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KB/km

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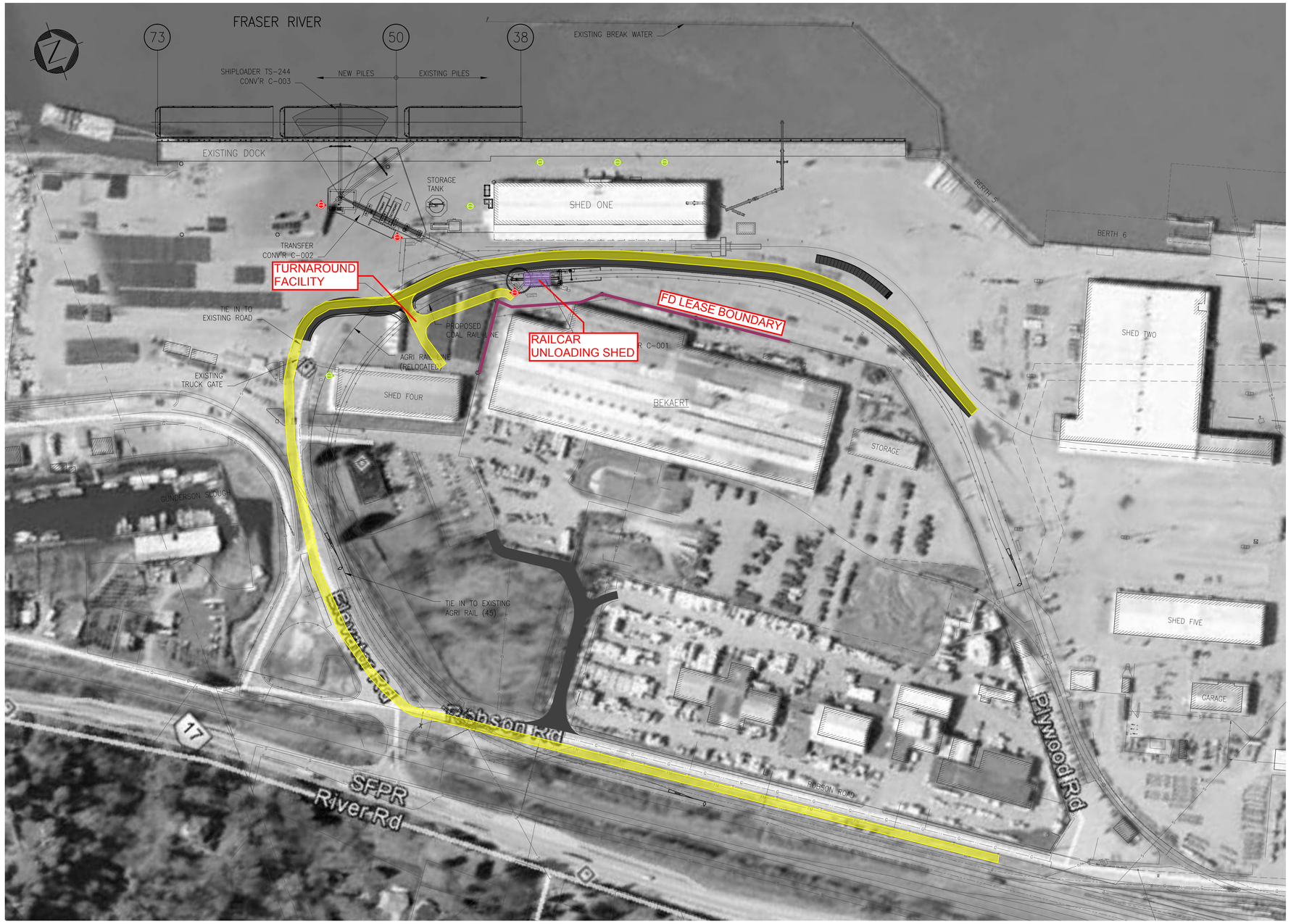

CFT Engineering Inc.

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CODE COMPLIANCE DRAWING
PROJECT # : 6772
DRAWN BY : JC
DATE : MAY 27, 2013
REVISED : APRIL 10, 2014
REVISED : JULY 21, 2014
REVISED : SEPTEMBER 30, 2014
REVISED : MARCH 30, 2015

LEGEND

FSD LEASE BOUNDARY	
SURFACE FIRE HYDRANT	
UNDERGROUND HYDRANT ASSEMBLY	

REF.	DWG. NUMBER	DESCRIPTION

REFERENCE DRAWINGS / DESIGN STANDARDS

CLIENT PROJECT No:

CWA ACAD FILE: 14028-100-GA-000A.DWG

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	APPROVED
–	–	–	–	–	–		MAL

ISSUES / REVISIONS

* HAND INITIALS ON FILE

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DRAWN BY: SEC

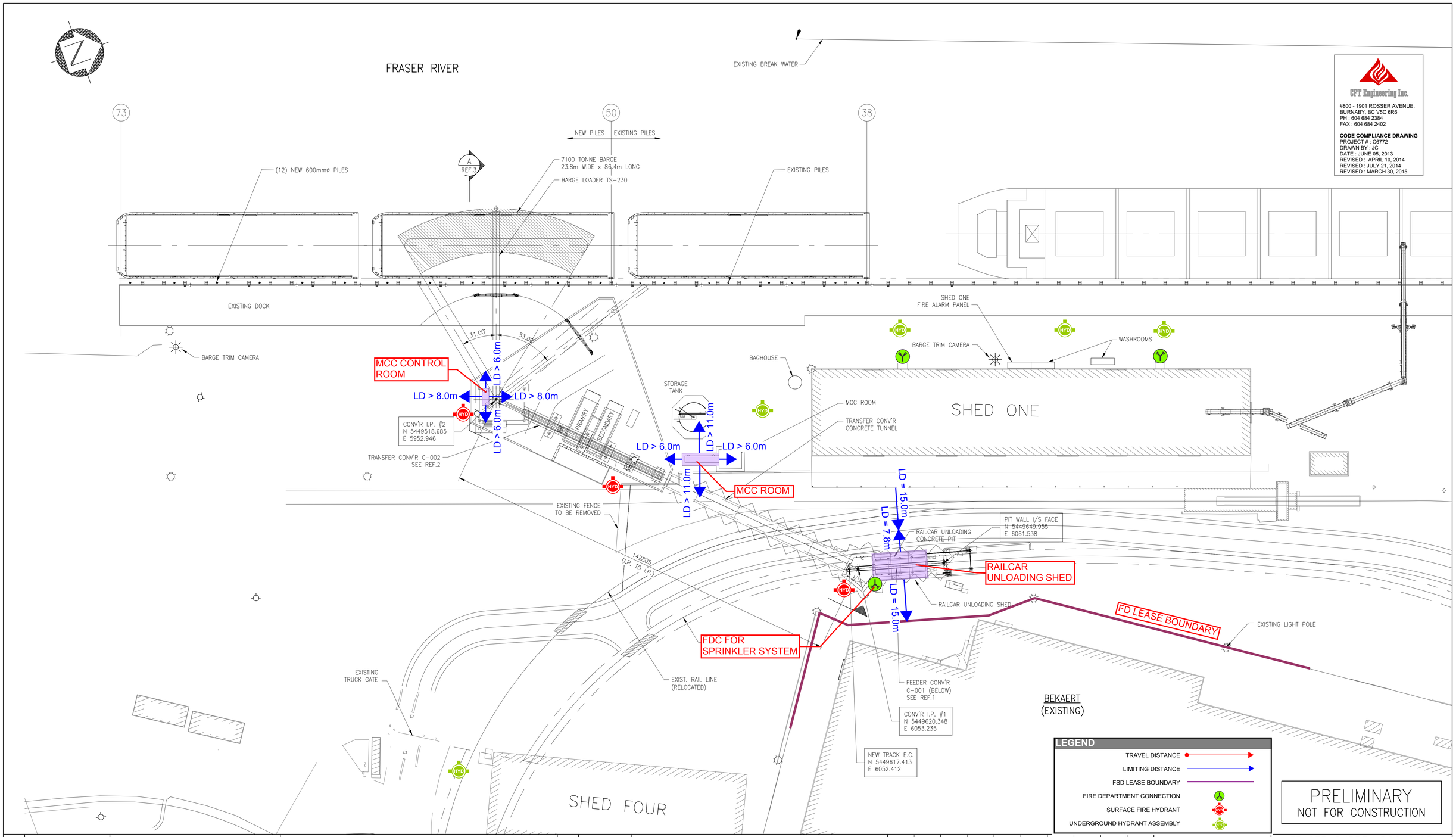
SCALE: 1:1500

FRASER SURREY DOCKS LP
PACIFIC RIM STEVEDORING
SURREY, B.C.

FSD DTB COAL FACILITY

OVERALL
SITE PLAN

PROJECT No.	AREA	DEPT.	DWG. No.	REV.
14028	100	GA	000	–



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CODE COMPLIANCE DRAWING
PROJECT # : C6772
DRAWN BY : JC
DATE : JUNE 05, 2013
REVISED : APRIL 10, 2014
REVISED : JULY 21, 2014
REVISED : MARCH 30, 2015

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION
3	14028-100-GA-008	TRANSFER CONVEYOR – GENERAL SECTION
2	14028-100-MH-051	TRANSFER CONVEYOR – GENERAL ARRANGEMENT
1	14028-100-MH-021	FEEDER CONVEYOR – GENERAL ARRANGEMENT

REFERENCE DRAWINGS / DESIGN STANDARDS

CLIENT PROJECT No:

CWA ACAD FILE: 14028-100-GA-001A.DWG

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	APPROVED
P7	2014-12-30	RE-ISSUED FOR PERMIT	SEC	MAL	SJM		MAL
P6	2014-12-23	ISSUED FOR TENDER	SEC	MAL	SJM		MAL
P5	2014-12-16	RE-ISSUED FOR PERMIT	SJM	MAL	SJM		MAL
P4	2014-10-31	ISSUED FOR PERMIT	SJM	MAL	SJM		MAL
P3	2014-10-17	GENERAL UPDATE (SECONDARY AGRI RAIL ADDED)	SJM	MAL	SJM		MAL
P2	2014-07-18	ISSUED FOR TENDER	SJM	MAL	SJM		MAL
P1	2014-07-17	ISSUED FOR TENDER	SJM	MAL	SJM		MAL

ISSUES / REVISIONS

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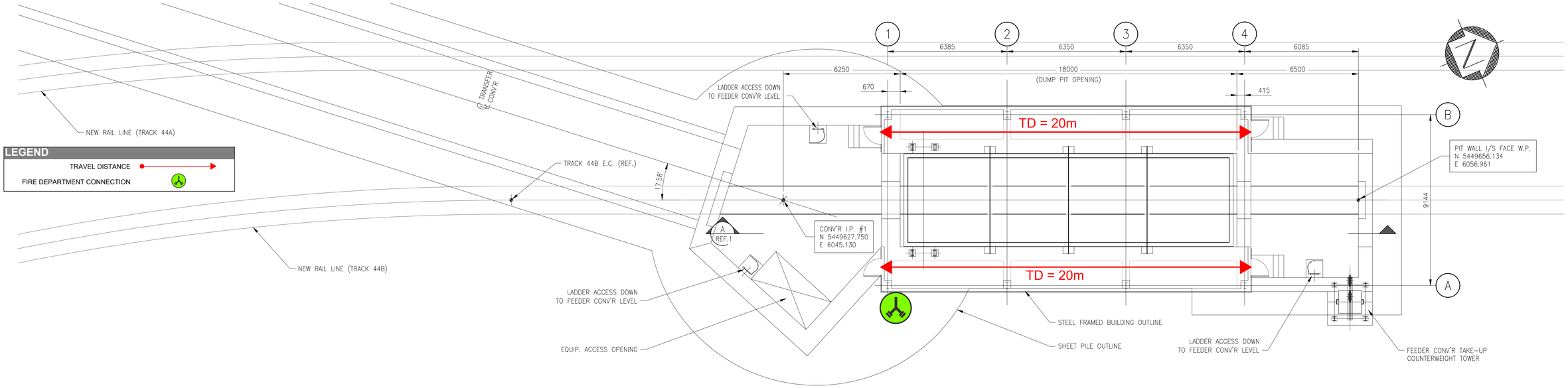
DRAWN BY: SJM
SCALE: 1:600

FRASER SURREY DOCKS LP
PACIFIC RIM STEVEDORING
SURREY, B.C.

FSD DTB COAL FACILITY

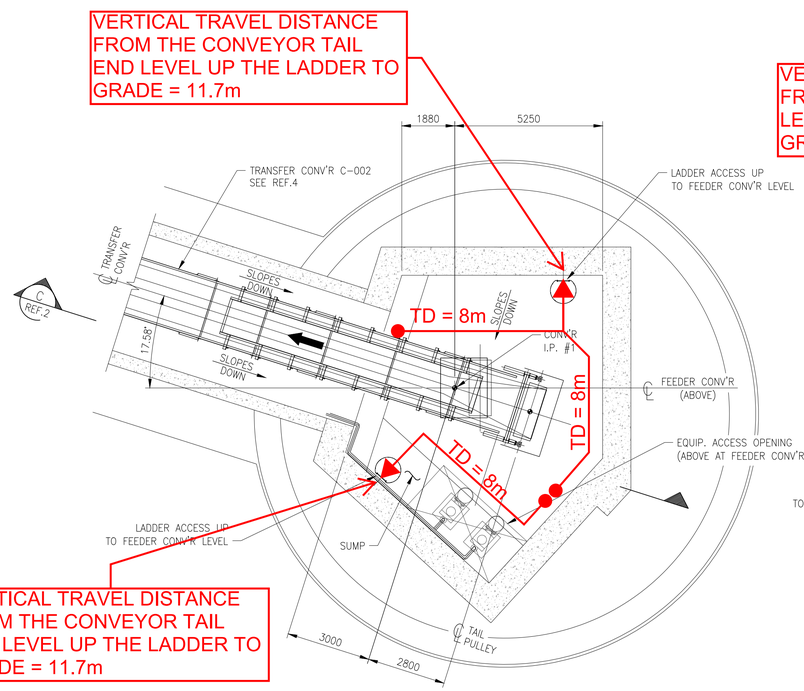
SITE PLAN

PROJECT No.	AREA	DEPT.	DWG. No.	REV.
14028	100	GA	001	P7



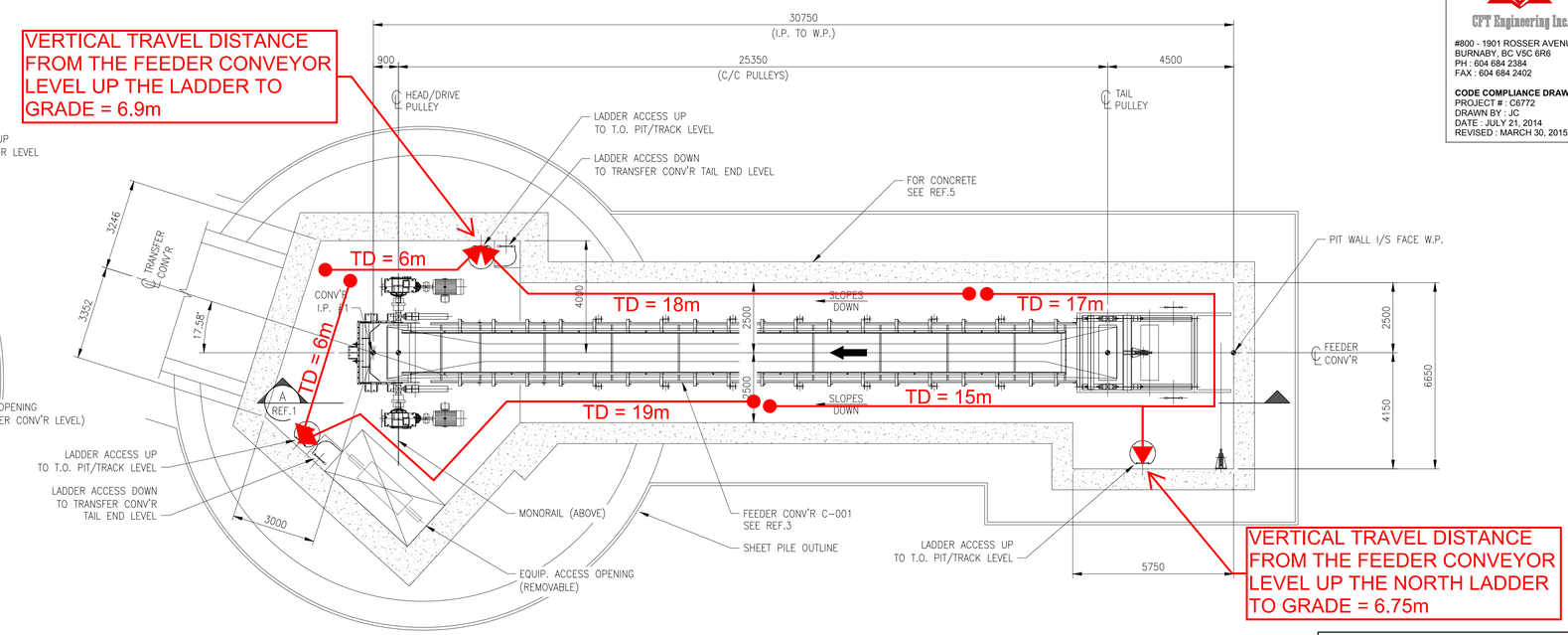
PLAN AT T.O. PIT/TRACK LEVEL

SCALE 1:100



PLAN AT TRANSFER CONVEYOR TAIL END LEVEL

SCALE 1:100



PLAN AT FEEDER CONVEYOR LEVEL

SCALE 1:100

CPT Engineering Inc.
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CODE COMPLIANCE DRAWING
PROJECT # : C6772
DRAWN BY : JC
DATE : JULY 21, 2014
REVISED : MARCH 30, 2015

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION
5	14028-100-CO-010/011	RAILCAR UNLOADING AREA – CONCRETE OUTLINE PLANS
4	14028-100-MH-051	TRANSFER CONVEYOR – GENERAL ARRANGEMENT
3	14028-100-MH-021	FEEDER CONVEYOR – GENERAL ARRANGEMENT
2	14028-100-GA-007	GENERAL ARRANGEMENT – SECTIONS – SHEET 2
1	14028-100-GA-006	GENERAL ARRANGEMENT – SECTIONS – SHEET 1

REFERENCE DRAWINGS / DESIGN STANDARDS

CLIENT PROJECT No:

CWA ACAD FILE: 14028-100-GA-005 TO 008_2014-12-9.DWG

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	APPROVED
P2	2014-10-31	ISSUED FOR PERMIT	SJM	MAL	SJM		MAL
P1	2014-07-18	ISSUED FOR TENDER	SJM	MAL	SJM		MAL

ISSUES / REVISIONS

* HAND INITIALS ON FILE

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FRASER SURREY DOCKS LP
PACIFIC RIM STEVEDORING
SURREY, B.C.

FSD DTB COAL FACILITY

RAILCAR UNLOADING AREA
GENERAL ARRANGEMENT
PLAN VIEWS

PROJECT No.	AREA	DEPT.	DWG. No.	REV.
14028	100	GA	005	P2

DRAWN BY: SJM | SCALE: AS NOTED

APPENDIX B

5.3.7.3.4 All fire suppression equipment and systems shall be tested after installation in accordance with the manufacturer's or designer's recommendations.

5.3.7.3.4.1 Testing shall not require the discharge of suppressant unless there is no other manner in which the reliability and integrity of the system can be verified.

5.3.7.3.5 An installation-and-maintenance or owner's manual that describes system operation and maintenance requirements shall be provided for all fire suppression equipment.

5.3.7.3.6* In accordance with the manufacturers' or designers' recommended inspection and maintenance procedures and schedules, but not to exceed every 6 months, all fire suppression systems, including alarms, shutdowns, and other associated equipment, shall be thoroughly examined and checked for proper operation by competent personnel.

5.3.7.3.6.1 Any equipment found deficient shall be repaired or replaced, and the system retested for proper operation.

5.3.7.3.6.2 Between regular maintenance examinations or tests, the system shall be inspected visually, in accordance with the manufacturer's or designer's recommended schedule.

5.3.7.3.6.3 Testing shall be in accordance with the applicable NFPA standards.

5.3.7.3.7 Fire suppression systems shall be maintained in operating condition at all times.

5.3.7.3.8 Use, impairment, and restoration of the system shall be reported to the mine operator.

5.3.7.3.9 All persons who can be expected to inspect, test, maintain, or operate a fire suppression system shall be trained to perform their intended tasks.

5.3.7.3.10 Where inadvertent discharge of the fire suppression system during servicing could result in injury to personnel, provisions shall be made to safeguard against accidental actuation of the system.

5.3.7.3.11 All operators, supervisors, and maintenance personnel of self-propelled and mobile equipment shall be trained in the use of fire suppression equipment.

Chapter 6 Coal Processing

6.1 General.

6.1.1 Materials and Construction.

6.1.1.1 Coal mine surface buildings and structures, housing, and supporting coal-processing and coal-handling equipment shall be of noncombustible construction.

6.1.1.2 Dry coal screening, crushing, dry cleaning, and other operations producing coal dust shall be conducted in open structures to prevent the accumulation of dust concentration levels that can create explosion hazards.

6.1.1.2.1 Where open structures are impractical, enclosed buildings shall be provided with explosion venting in accordance with 6.2.3 and shall be located so as to minimize fire and explosion exposure to major buildings and equipment.

6.1.1.2.2 Location of the processes described in 6.1.1.2 in the main plant building shall be permitted, provided the dust-producing area is equipped with explosion venting in accordance with 6.2.3 and is separated from the remainder of the building by construction designed to withstand the pressure buildup from an explosion prior to pressure relief by means of explosion vents.

6.1.2 Coal Dust Control.

6.1.2.1 Dedusters.

6.1.2.1.1 All dedusting equipment shall be connected directly to a suction system capable of moving enough air to prevent the leakage of dust from the system.

6.1.2.1.2 The suction system shall discharge the dust-laden air by the shortest possible route to collectors outside the building.

6.1.2.2* Pneumatic Cleaners.

6.1.2.2.1 Dust-collecting systems with suction hoods at the cleaners, suction ducting that maintains at least a 20 m/sec (4000 ft/min) air velocity, and dust collectors having pressure release venting shall be installed.

6.1.2.2.2 Belt conveyor–type transfers and loading points associated with the cleaners shall be hooded similarly and connected to dust collectors.

6.1.3 Coal Storage.

Coal storage facilities shall be in accordance with 9.5.2.

6.2 Fire and Explosion Prevention.

6.2.1 Electrical Classification of Hazard.

6.2.1.1 Plant areas of open construction where coal dust or any combustible gases liberated from the coal are dispersed to the open atmosphere shall be classified nonhazardous.

6.2.1.2 Plant areas isolated from the coal process, such as control rooms, electrical equipment rooms, or substations, that are provided with ventilation to prevent the accumulation of combustible gases or coal dust shall be classified nonhazardous.

6.2.1.3 Enclosed areas of processing plants where coal is wet to prevent particles from becoming airborne or where dry coal dust does not accumulate shall be classified nonhazardous.

6.2.1.4* Enclosed areas where the failure or malfunction of the ventilation would result in the accumulation of explosive concentrations of methane gas shall be designated as Class I, Division 2 locations in accordance with Article 500 of *NFPA 70, National Electrical Code.*

6.2.1.4.1* Electrical equipment approved as "permissible" by the Mine Safety and Health Administration (MSHA) shall be acceptable in locations classified Class I, Division 1.

6.2.1.5 Areas of a processing plant normally designated as Class I shall be permitted to be considered nonhazardous, provided the following conditions are met:

(1) Ventilation to prevent an accumulation of an explosive or ignitible mixture of gases
(2) Failsafe continuous methane monitoring designed to sound an alarm when the methane–air mixture reaches 20 percent of the lower explosive level (LEL) or 1 percent methane by volume
(3) An interlock to stop the process equipment automatically when the methane–air mixture reaches 40 percent of the LEL or 2 percent methane by volume

7.6.8.6 Dispensing Class II combustible liquid from containers or tanks shall be accomplished by an approved transfer pump or by gravity flow.

7.6.8.6.1 Where needed, containers or tanks shall be equipped with an approved vent.

7.6.8.6.2 If a manual valve is used, it shall be of the self-closing type without a latch-open device.

7.6.8.7 Spillage shall be cleaned up.

7.6.8.8 Remaining residue shall be covered with an oil absorbent or rock dust.

Chapter 8 Mine Surface Buildings

8.1 Construction.

8.1.1 This chapter shall include mine offices, bathhouses, warehouses, vehicle storage, and shops.

8.1.2 Offices over 1394 m^2 (15,000 ft^2), warehouses over 929 m^2 (10,000 ft^2), and shops over 465 m^2 (5000 ft^2) shall be constructed of noncombustible materials or provided with an automatic sprinkler system installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems.*

8.2 Fire Prevention.

8.2.1 No smoking shall be allowed in warehouses.

8.2.2 Combustible storage shall be maintained at least 0.9 m (3 ft) from electrical panels and electric resistance heaters.

8.2.3 Oily waste or rags that can create a fire hazard shall be placed in covered metal containers.

8.2.4 Battery rooms shall be in accordance with *NFPA 70, National Electrical Code,* Article 480.

8.2.4.1 Battery-charging installations shall be located in a designated area that is protected against damage from mobile equipment.

8.2.4.2 Each battery-charging installation shall be equipped with the following:

(1) Approved portable multipurpose fire extinguisher(s)
(2) Ventilation for the removal of generated gases from charging batteries
(3) A means for flushing spilled electrolyte

8.3 Life Safety.

8.3.1 Two means of egress shall be provided from multistory buildings.

8.3.2 For office, bathhouse, and warehouse areas, emergency lighting shall be provided in each stairwell or hallway that is the means of egress in accordance with NFPA *101, Life Safety Code.*

8.3.3 For office, bathhouse, and warehouse areas, emergency exit signs shall be provided along the means of egress.

8.4 Flammable and Combustible Liquids.

8.4.1 All storage and handling of flammable and combustible liquids shall conform to the guidelines established in NFPA 30, *Flammable and Combustible Liquids Code.*

8.4.2 The quantity of flammable liquids and aerosols stored outside a flammable liquids storage cabinet shall not exceed 94.6 L (25 gal).

8.4.3 Other than in shops, the quantity of combustible liquids outside a flammable liquids storage cabinet or room constructed in accordance with NFPA 30, *Flammable and Combustible Liquids Code,* shall not exceed 454 L (120 gal).

8.4.4 Dispensing of flammable or combustible liquids in warehouses shall be prohibited.

8.4.5 Storage of acetylene, oxygen, or other welding gases inside warehouses shall be prohibited.

8.4.6 Drip pans shall be provided to catch leakage or spillage wherever flammable or combustible liquids are dispensed.

8.4.7 Fusible link–actuated automatic closers shall be provided on all parts cleaning tanks.

8.5* Compressed Gas Storage and Usage. Storage and use of compressed gases in and around mine buildings shall be in accordance with Section 7.1.

8.6 Fire Detection and Protection.

8.6.1 For multistory office buildings, a central station or proprietary alarm system shall be installed in accordance with *NFPA 72, National Fire Alarm and Signaling Code.*

8.6.1.1 Alarms shall include smoke detectors, duct detectors, and manual pull stations.

8.6.1.2 In addition, if sprinklers are installed, water flow, valve tamper, and low building temperature alarms shall be provided.

8.6.1.3 All equipment shall be listed or approved for its intended use.

8.6.2* If sprinkler systems are installed, they shall be in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems.*

8.6.3* If fire hydrants are installed, they shall be in accordance with NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances.*

8.6.4 If a building is more than two stories high, a standpipe system shall be installed in accordance with NFPA 14, *Standard for the Installation of Standpipe and Hose Systems.*

8.6.5 If a gaseous fire suppression system is installed in a computer or telephone equipment room, it shall be in accordance with NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems.*

8.6.6* Fire extinguishers shall be provided and maintained in accordance with NFPA 10, *Standard for Portable Fire Extinguishers.*

8.6.6.1 Fire extinguishers shall be inspected at least every 6 months.

Chapter 9 Coal Conveyance and Storage

9.1* Conveyors — General.

9.1.1* Belt conveyors shall meet the following minimum requirements:

(1) Belt alignment limit switches shall be provided on conveyors to shut down belts that are tracking improperly.
(2) Slip switches shall be provided to detect a slipping or jammed belt and shall be interlocked to shut off driving

power when the belt stops or slows down by more than 20 percent of its normal speed.

(3) Slip switches shall be tested on a weekly basis.

(4) Shutoff power shall be provided on contributing conveyors to prevent any operating conveyor from discharging material to a stopped downstream conveyor.

(5) Means shall be provided to remove tramp metal and other foreign objects as early in the handling process as possible.

(6) Hydraulic systems for belt alignment, if provided, shall use only listed fire-retardant hydraulic fluids or shall be protected by an automatic fire protection system.

(7) Alarms shall annunciate in the operator's control room.

(8) Electrical equipment shall be classified as Class II, Division 2, Group F in all areas where required by *NFPA 70, National Electrical Code*.

(9) Guarding for machinery in the drive area and at other points along the belt shall be made of noncombustible material.

9.1.2* Structures supporting belt conveyors shall be designed to prevent coal accumulations.

9.1.2.1 The design shall include any surface near the belting that can catch and retain fine coal liable to ignite spontaneously.

9.1.3 Consideration shall be given to the possibility of static electrical discharge at the conveyor head and tail pulleys located in dry climates where bituminous and lower ranking–type coals are handled.

9.1.3.1 Factors that shall be considered are belting materials, belt speed, and housekeeping of spilled coal dust.

9.1.3.2 Where such conditions as described in 9.1.3 exist, the use of static dissipators or eliminators shall be considered.

9.1.4 Attention shall be given to the prevention of and cleaning of accumulations of fine coal dust beneath and close to belt conveyors.

9.2 Overland Conveyors.

9.2.1 Chute plug alarms shall be provided for long runs of belt or critical conveyor systems.

9.2.2 The conveyor path shall be kept free of all grass, weeds, trash, or any other material that could create an exposure to the belt should it catch on fire.

9.2.3 Motor control center (MCC) buildings for conveyor systems shall be kept free of accumulations of coal dust.

9.3 Below-Grade Reclaim Conveyors.

9.3.1 Methane detection shall be provided in below-grade reclaim conveyor areas.

9.3.2 Equipment shall be interlocked to de-energize upon detection of a 2 percent concentration of methane.

9.3.3 Portable methane detectors are an acceptable alternative to fixed detectors, provided a reading is taken once per shift.

9.4 Underground Conveyors.

9.4.1 Underground conveyor belts shall be of a flame-resistant material and approved by the authority having jurisdiction.

9.4.2 Entries in which belt conveyors are installed shall be kept free of accumulations of coal and coal dust around the belt idlers, pulleys, and belt edges and shall be rock-dusted.

9.4.3* Fixed combustible material such as posts, cribbing, and roof supports shall be guarded from contact with the belt by the use of noncombustible material or by distance and shall be located at a distance of at least 152.4 mm (6 in.) from any idler or pulley.

9.4.4 Belt conveyor installations shall use a support structure without a deck between the upper and lower belt flights.

9.4.5 Belts that carry the load of the belt on a low-friction metal deck without rollers shall be permitted to be used.

9.4.6 Automatic Fire Suppression Systems at the Belt Drive.

9.4.6.1 Deluge water spray systems, foam systems, closed-head sprinkler systems, or dry-chemical systems automatically actuated by rise in temperature shall be installed at main and secondary belt conveyor drives.

9.4.6.2 Fire suppression systems shall extend to the drive areas of belt conveyors, including drive motor(s), reducer, head pulley, and belt storage unit (takeup), including any hydraulic power unit; its electrical controls; and the top and bottom of the first 15.2 m (50 ft) of belt from the drive on the downwind side.

9.4.6.3 Piping for the deluge, foam, or closed-head sprinkler system shall be metal and listed for sprinkler applications.

9.4.6.3.1* Sprinkler piping shall be supported by UL-listed pipe hangers or other substantial metal supports such as angle iron, U bolts, or heavy chain.

9.4.6.4 The application rate shall not be less than 10.2 L/min/m^2 (0.25 gpm/ft^2) of the top surface of the top belt.

9.4.6.5 The discharge shall be directed at both the upper and the bottom surface of the top belt and the upper surface of the bottom belt.

9.4.6.6 The water supply shall be free of excessive sediment and corrosives and provide the required flow for not less than 10 minutes. A strainer with a flush-out connection and manual shutoff valve shall be provided.

9.4.6.7 Maximum distance between nozzles on a branch line shall not exceed 2.4 m (8 ft).

9.4.6.8 The system shall be interlocked to shut down the conveyor and provide an audible and a visual alarm.

9.4.6.9 The components of the system shall be located so as to minimize the possibility of damage by roof fall or by the moving belt and its load.

9.4.6.10 Fire suppression systems shall also comply with 4.3.3.3.

9.4.6.11 Deluge water spray systems shall meet the requirements of 9.4.6.11.1 through 9.4.6.11.3.

9.4.6.11.1 The system shall be activated by heat detectors.

9.4.6.11.1.1 Heat detectors shall be located at the belt drive, hydraulic takeup unit (unless fire-resistive fluid is used), discharge roller, and the roof above the conveyor.

9.4.6.11.1.2 Heat detectors at the roof line should be spaced 2.4 m to 3.0 m (8 ft to 10 ft) apart along the entire length of the protected area of the belt.

9.4.6.11.2 The nozzles shall be full cone, corrosion resistant, and provided with blow-off dust covers.

9.4.6.11.3 A closed sprinkler head shall be used over the electrical controls.

9.4.6.12 Foam systems shall meet the requirements of 9.4.6.12.1 through 9.4.6.12.4.

9.4.6.12.1 The system shall be activated by heat detectors.

9.4.6.12.1.1 Heat detectors shall be located at the belt drive, hydraulic takeup unit (unless fire-resistive fluid is used), discharge roller, and the roof above the conveyor.

9.4.6.12.1.2 Heat detectors at the roof line should be spaced 2.4 m to 3.0 m (8 ft to 10 ft) apart along the entire length of the protected area of the belt.

9.4.6.12.2 The nozzles shall be full cone, corrosion resistant, and provided with blow-off dust covers.

9.4.6.12.3 The system shall have a capacity to last 25 minutes.

9.4.6.12.4 A closed sprinkler head should be used over the electrical controls.

9.4.6.13 Sprinkler systems shall meet the following requirements:

(1) The sprinklers shall be installed in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems*, as far as practical, and shall have components that have been listed.
(2) The water supply shall be capable of supplying a constant flow of water with all heads functioning for a period of 10 minutes.
(3) The sprinkler head activation temperature shall not be less than 65.6°C (150°F) or greater than 148.9°C (300°F).
(4) *Sprinklers shall be kept free of excessive rock dust, muck, conveyor string, or any other material that can block the discharge or insulate the fusible link.

9.4.6.14 Maintenance and Testing. Fire suppression systems shall be maintained and tested in accordance with 4.3.3.4.

9.4.7 Manual Extinguishing.

9.4.7.1 Water lines shall be installed parallel to the entire length of belt conveyors and shall be equipped with fire taps with valves at 91.4 m (300 ft) intervals.

9.4.7.2 The threads on the hose taps shall be protected against dirt and rock grit that can prevent a quick connection.

9.4.7.3 The hose tap at the belt drive area shall be at least 15.2 m (50 ft) upwind of the belt drive.

9.4.7.4* At least 152.4 m (500 ft) of fire hose with fittings shall be stored at strategic locations along the conveyor belt, that is, at transfer points, drive areas, and tailpieces.

9.4.7.5 For each conveyor belt exceeding 610 m (2000 ft) in length, an additional cache of materials as specified in 9.4.7.4 shall be provided.

9.4.7.6 For mines using a track haulage system, the same criteria as those in Section 9.2 through 9.2.3 shall be met.

9.4.7.7 The following materials shall be stored within 91.4 m (300 ft) or 5 minutes of a belt drive:

(1) 152.4 m (500 ft) of fire hose or a high-expansion foam device and 61 m (200 ft) of hose
(2) Tools to open a stopping between the belt entry and the adjacent intake entry
(3) 109 kg (240 lb) of rock dust

9.4.7.8 Foam.

9.4.7.8.1 The foam generator shall produce foam sufficient to fill 30.5 m (100 ft) of belt haulageway in not more than 5 minutes.

9.4.7.8.2 A 1-hour supply of foam shall be kept on hand.

9.4.7.9 The entry containing the main water line and crosscuts containing water outlets shall be accessible.

9.4.7.10 Suitable communication lines to the surface shall be provided in the belt haulageway or adjacent entry.

9.4.7.11 A crew consisting of at least five members for each shift shall be trained in fire-fighting operations. Fire drills shall be held at intervals not exceeding 6 months.

9.4.7.12 Two 9.1 kg (20 lb) dry-chemical extinguishers shall be located at the drive areas.

9.4.8* A dust suppression water spray system actuated by a "conflow" switch or similar device shall be provided at the belt feeder.

9.4.9 Electrical equipment shall be permissible where required by the authority having jurisdiction.

9.5* Coal Storage — General. Coal bins, bunkers, and silos shall meet the following requirements:

(1) Storage durations shall be limited to prevent spontaneous combustion.
(2) Equipment shall be of noncombustible construction designed to minimize coal hang-up.
(3) Means shall be provided to remove burning, wet, or smoldering coal so it can be disposed of without producing an explosion or a fire.

9.5.1 Storage Bins.

9.5.1.1 All interior bins handling dusty material shall be vented in accordance with 6.2.2.

9.5.1.2 Storage bins for coal shall be located so that sources of heat not intended specifically to control the temperature of coal do not raise the temperature of the coal in the bin, causing spontaneous combustion materially.

9.5.2 Coal Silos.

9.5.2.1 Coal shall not be stored in silos and bunkers for long periods. If coal must be stored for a long period, air entrainment shall be prevented using the following methods:

(1) Covering the top of the stored coal with a binder material
(2) Inerting the stored coal with recommended inert gas

9.5.2.2 Areas in the storage (hideouts) that can allow pockets of coal to form, dry, and combust spontaneously shall be removed.

9.5.2.3 Storage silos shall be constructed of noncombustible material.

9.5.2.4 Electrical equipment shall be installed to meet the requirements of *NFPA 70, National Electrical Code*, in effect at the time of installation.

9.5.2.5 If a dust collector is provided, it shall be equipped with explosion relief panels in accordance with NFPA 68, *Standard on*

Explosion Protection by Deflagration Venting. The dust collector shall be grounded and have antistatic, fire-resistant bags.

9.5.2.6 Wash-down hoses shall be provided at the bottom of the silo.

9.5.2.7 Dual high-level cutoff switches shall be provided for the silo. The feed conveyor shall be interlocked to shut down on the low–high indication.

9.5.2.8 The silo shall be maintained on a regular cleaning schedule to minimize the buildup of coal beneath the hopper and other areas inside the silo.

9.5.2.9 Deluge water spray systems, foam systems, closed-head sprinkler systems, or dry-chemical systems automatically actuated by rise in temperature shall be installed over the belt drive areas on top of a silo.

9.5.3 Stacker Tubes and Coal Storage Piles.

9.5.3.1 Coal piles shall be designed to minimize the entrainment of air.

9.5.3.1.1 Minimization shall be permitted by development of a compacted edge around the pile.

9.5.3.1.2 The edge described in 9.5.3.1.1 shall be sealed with binder to aid in sealing.

9.5.3.2 Hot spots or areas of spontaneous combustion shall be removed by digging.

9.5.3.3 The use of water for extinguishment shall be used at a minimum.

9.5.3.4 Active storage piles shall be worked to prevent dead pockets of coal, a potential source of spontaneous heating.

9.5.3.5 Coal piles shall not be located above heat sources, such as steam lines, or sources of air, such as manholes.

9.5.3.6 Coal placed in long-term storage shall be piled in layers, appropriately spread, and compacted prior to the addition of subsequent layers to reduce air movement and to minimize water infiltration into the pile.

9.5.3.7 Where possible, storage piles shall be arranged to allow access to the pile with earth-moving equipment in the event of developing hot spots or fire.

Chapter 10 Truck, Rail, and Barge Loadouts

10.1 Construction.

10.1.1 The loadout shall be constructed of noncombustible material.

10.1.2 Conveyor systems shall be in accordance with Section 9.1.

10.2 Fire Prevention.

10.2.1 No smoking shall be allowed in the loadout control room.

10.2.2* Loadout control rooms shall be designed, constructed, and maintained to reduce the chances of coal dust entering the room.

10.2.3 Combustible storage shall be maintained at least 0.9 m (3 ft) from all electrical panels, gas-fired heaters, and electric resistance heaters.

10.2.4 Trash and other unnecessary combustibles shall not be allowed to accumulate in the loadout control room.

10.2.5 Motor control centers shall be thermographically scanned on an annual basis to identify hot spots and loose electrical connections.

10.2.6 Hydraulic equipment shall have the following alarms interlocked to shut down the equipment:

(1) Low oil pressure
(2) High oil temperature
(3) Low oil level

10.3 Life Safety.

10.3.1 Two means of egress shall be provided from the loadout control room if the room is more than two levels high.

10.3.2 For multistory buildings, emergency lighting shall be provided in accordance with NFPA *101, Life Safety Code.*

10.3.3 For multistory buildings, emergency exit signs shall be provided along the means of egress.

10.4 Fire Detection and Protection.

10.4.1 A smoke detector system shall be installed in the loadout control room in accordance with *NFPA 72, National Fire Alarm and Signaling Code.*

10.4.1.1 The smoke detector system shall actuate an audible and visual alarm system.

10.4.1.2 For infrequently occupied or remote locations, the system shall send an alarm to a constantly attended location.

10.4.2* A gaseous fire suppression system shall be installed in loadout control rooms that are not regularly occupied and located in remote areas.

10.4.3 An automatic fire suppression system shall be installed to protect hydraulic pumps that have a capacity over 189.3 L (50 gal).

10.4.3.1 The system shall be actuated by a heat detector system.

10.4.3.2 The system shall be interlocked to shut off the power to the unit.

10.4.3.3 A listed fire-resistive fluid shall be an acceptable alternative to an automatic fire suppression system.

10.5 Manual Fire Fighting.

10.5.1* Fire extinguishers shall be provided in accordance with NFPA 10, *Standard for Portable Fire Extinguishers.*

10.5.2 For multistory buildings, an emergency response plan shall be developed with the input of the local fire department.

10.5.3 For areas subject to flood, an emergency response plan shall be developed to include fire-fighting procedures during a flood.

Chapter 11 Emergency Response, Manual Fire Fighting, and Training

11.1* Emergency Procedures.

11.1.1 Emergency procedures shall be provided to instruct all miners in the location and use of fire-fighting equipment, location of escapeways and exits, and evacuation procedures.

APPENDIX C

JENIKE & JOHANSON

BULK MATERIAL 1: Decker coal

PARTICLE SIZE As Rec'd

MOISTURE CONTENT 16%

SECTION IIA. SIEVE ANALYSIS

DESCRIPTION : Reference

U.S. SIEVE NUMBER	OPENING SIZE (inches)	(mm)	% WT. RETAINED
1.0	1.0000	25.400	0.00
1/4	0.2500	6.350	0.00
#6	0.1320	3.353	11.10
#12	0.0661	1.679	27.28
#20	0.0334	0.848	22.19
#40	0.0165	0.419	15.73
#100	0.0059	0.150	14.49
PAN			9.21
			100.00

APPENDIX D

Overview of dust explosibility characteristics

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Abstract

This paper is an overview of and introduction to the subject of dust explosions. The purpose is to provide information on the explosibility and ignitability properties of dust clouds that can be used to improve safety in industries that generate, process, use, or transport combustible dusts. The requirements for a dust explosion are: a combustible dust, dispersed in air, a concentration above the flammable limit, the presence of a sufficiently energetic ignition source, and some confinement. An explosion of a fuel in air involves the rapid oxidation of combustible material, leading to a rapid increase in temperature and pressure. The violence of an explosion is related to the rate of energy release due to chemical reactions relative to the degree of confinement and heat losses. The combustion properties of a dust depend on its chemical and physical characteristics, especially its particle size distribution. In this paper, the explosion characteristics of combustible dusts will be compared and contrasted with those of flammable gases, using methane as an example. These characteristics include minimum explosible concentration, maximum explosion pressure, maximum rate of pressure rise, limiting oxygen concentration, ignition temperature, and amount of inert dust necessary to prevent flame propagation. The parameters considered include the effects of dust volatility, dust particle size, turbulence, initial pressure, initial temperature, and oxygen concentration. Both carbonaceous and metal dusts will be used as examples. The goal of this research is to better understand the fundamental aspects of dust explosions.

1. Introduction

In industries that manufacture, process, generate, or use combustible dusts, an accurate knowledge of their explosion hazards is essential. Various books have been published since 1980 on the general subject of the explosion hazards of dusts and powders (Bartknecht 1981, 1989, 1993; Field, 1982; Nagy & Verakis, 1983; Cashdollar & Hertzberg, 1987; Eckhoff, 1991). The present paper is an update of a previous Pittsburgh Research Laboratory[1] (PRL) paper (Hertzberg & Cashdollar, 1987) on the general topic of the explosion hazards of dusts. The basic variables that influence the characteristics of a dust explosion will be discussed in general terms without specific reference to particular practical systems. One purpose of this paper is to provide assistance and guidance to the practising safety engineer at a plant regarding the important variables in dust explosibility. Both carbonaceous and metal dusts are used as examples of combustible dusts. Although many of the examples in this paper use coal dust, the concepts are applicable to other dusts as well.

This paper is not meant to be an overview of the many areas of dust explosion research throughout the world. Instead, it is only meant to be an overview of some of the dust explosibility characteristics that are important for safety engineers to consider at industrial plants.

2. Dust explosion requirements

The three requirements for combustion are a fuel, an oxidizer (usually air), and an adequate heat or ignition source. This is often called the "fire triangle". The fuel can be any material capable of reacting rapidly and exothermically with an oxidizing medium. In this case, the fuel is a combustible dust. For a dust explosion, the dust must be dispersed in the air at the same time that the ignition source is present. The resulting rapid oxidation of the fuel dust leads to a rapid increase in temperature and therefore pressure. This explosion may be a deflagration or a detonation, depending on the rate of reaction

[1] The Pittsburgh Research Laboratory was part of the U.S. Bureau of Mines before transferring to the National Institute for Occupational Safety and Health (NIOSH) in October 1996.

and resulting burning velocity. The discussion in this paper is mainly confined to deflagrations. The destructive pressure forces of an explosion can destroy structures and endanger personnel. The violence of an explosion is dependent on the rate of energy release due to chemical reactions relative to the degree of confinement and heat losses. The requirements for a dust explosion are often called (Stephan, 1990) the "explosion pentagon"—consisting of fuel, dispersion/suspension, oxidizer, heat/ignition source, and confinement. The confinement is usually the walls of the equipment or building in which the dust is dispersed, but it could also come from self-confinement if the reaction is fast enough. It is possible to have a destructive explosion even in open air if the reaction is so fast that pressure builds up in the dust cloud faster than it can be released at the edge of the cloud.

Whether the reacting material is a gas or a dust, the combustion products are usually gases so that the explosion process in a closed system is most simply understood in terms of the ideal gas law:

$$PV = nRT = \frac{m}{M}RT \tag{1}$$

where the absolute pressure, P, times the system volume, V, is proportional to the temperature, T. The proportionality constants are the number of moles, n, and the universal gas constant, R. The number of moles is equal to the mass of gas, m, divided by the average molecular weight, M. For a typical accidental explosion, air is usually the oxidant and the fuel may be a dust, gas, or hybrid mixture. Because air consists mainly of nitrogen, there is usually little change in the number of moles of gas during combustion. Therefore, to a first approximation, a rapid combustion reaction in a closed system results in:

$$\frac{P_{max}}{P_0} = \frac{T_b}{T_0} \tag{2}$$

where P_{max} is the maximum absolute explosion pressure, P_0 is the initial absolute pressure, T_b is the absolute temperature of the burned gas and T_0 is the initial absolute temperature. The faster the combustion reaction is, the more adiabatic the system will be, and the more nearly will the explosion pressure approximate the ideal relation in Eq. (2). If the number of moles of gas changes significantly during combustion or if the explosion vents from the container volume, the maximum explosion pressure will be significantly changed.

In this paper, the terms "flammability" and "explosibility" are used interchangeably to refer to the ability of an airborne dust cloud and/or gas mixture to propagate a deflagration after it has been initiated by a sufficiently strong ignition source. Historically, the term "flammability" has been used more often for gases, and "explosibility" more often for dusts.

The mechanism of flame propagation for many dusts is combustion of flammable gases emitted by particles heated to the point of vaporization or pyrolysis (Hertzberg, Zlochower & Cashdollar, 1988b; Cashdollar, Hertzberg & Zlochower, 1989). Some other dusts can propagate a flame through direct oxidation at the particle surface (Hertzberg, Zlochower & Cashdollar, 1992). For either mechanism, a finer size of dust is likely to react faster than a larger size of dust of the same material. Particle shape and porosity can also greatly affect the particle surface area and the reaction rates. Therefore, the dust particle size and shape are of primary importance in regard to dust explosibility characteristics. Dusts are often defined as material that is minus 20 mesh (<850 μm) (Stephan, 1990; Nagy, 1981) or minus 40 mesh (<420 μm) (NFPA, 1998). However, the larger dust particles participate inefficiently in the flame propagation process. It is the finer fraction of the dust particles that contributes the most to the hazard because the finer particles have a greater surface area per mass and therefore react faster. The finer dust particles are also more easily dispersed in air and remain airborne longer.

An example of a dust particle size distribution is shown in Fig. 1. The cumulative distribution is shown in Fig. 1A and the differential distribution in Fig. 1B as semi-logarithmic plots. The two types of size distributions are shown both as surface area weighted and as mass or volume weighted curves. The surface median

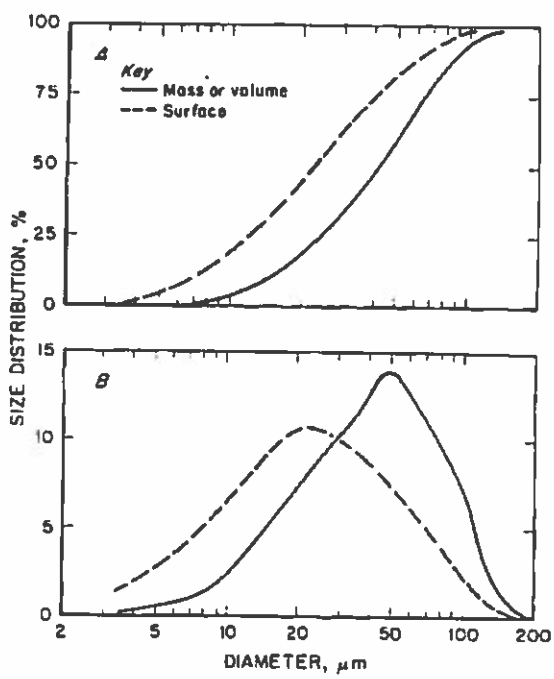

Fig. 1. Dust particle size distributions by surface area and mass: (A) cumulative distribution; (B) differential distribution.

diameter (23 μm) and the mass median diameter (42 μm) can be determined from the 50% points on the cumulative curves in Fig. 1A. The cumulative curve also shows that the dust has 82% by mass minus 200 mesh (<75 μm). The differential curves in Fig. 1B are often more useful in visualizing the size distribution. Other ways of identifying a representative particle size for the dust in Fig. 1 are the surface mean diameter ($\bar{D}_s$=30 μm) and the mass mean diameter ($\bar{D}_w$=50 μm), calculated from the data in Fig. 1B. Because the combustion of the dust cloud is greatly dependent on the surface area of the dust, a mean particle diameter based on surface area is perhaps more appropriate than one based on mass. Various books on particle size analysis (e.g. Allen, 1975; Irani & Callis, 1963), may be useful in better understanding this aspect of dusts. It should be noted that different particle size analysis instrumentation may give somewhat different results for the same dust because of the different particle sizing methods used.

The combustion properties of a dust depend on its chemical and physical characteristics, especially its particle size distribution. Published dust explosibility data can give an indication of the hazards associated with a particular type of dust. However, it is preferable to determine the explosibility characteristics of an industrial dust by test, because published data are for a particular size distribution that may be different from the dust in question. Particle shape and porosity are also important considerations in the explosibility of a dust. In general, shapes with greater surface area will propagate flame more readily and therefore be more hazardous.

It should be noted that there is no US standardized test for whether or not a dust is explosible. There are tests to determine whether a dust can be ignited by an electric spark (Dorsett, Jacobson, Nagy & Williams, 1960) or what the maximum explosion pressures (ASTM, 1999a) or minimum explosible concentrations (ASTM, 1999b) are using stronger chemical ignitors. One reason for this lack of an explosibility test is that the question of whether or not a dust can be ignited and propagate a flame depends greatly on the ignition source. However, different industries have different views about what would be an appropriate or likely ignition source. For some industries, it could be an electrostatic spark; for others, it could be a flame; and for the mining industry, it could a very large flame from blown-out explosives. Therefore, each industry has to decide what are the likely or possible ignition sources and which dusts could be ignited by them.

3. Laboratory equipment for dust explosibility evaluation

The explosibility characteristics of dust clouds are often measured in closed volume chambers. The 1.2-L Hartmann tube (Nagy & Verakis, 1983; Dorsett et al., 1960) is often used for preliminary screening tests and for minimum ignition energy (MIE) measurements. However, it may yield false negatives for dusts that are difficult to ignite with a spark but that are ignitable by stronger ignition sources. It is also not recommended (ASTM, 1999a) for measuring rates of pressure rise. The 20-L chambers are used for explosibility measurements such as maximum explosion pressures, maximum rates of pressure rise, minimum explosible concentrations, and inerting effects. An example of a 20-L laboratory chamber (Cashdollar & Hertzberg, 1985) is shown in Fig. 2. This is the standard laboratory test chamber designed and used at the PRL for studying the explosibility and inerting of combustible dusts. There is another style of 20-L chamber designed by R. Siwek (Bartknecht 1981, 1989; Siwek 1977, 1985, 1988) that is in wide use in Europe and elsewhere. There are also 1-m^3 (1000-L) chambers (Bartknecht 1981, 1989; Cashdollar & Chatrathi, 1993). The 1-m^3 chambers may give more realistic measurements of minimum explosible concentrations, maximum explosion pressures, and maximum rates of pressure rise, but the testing is more time consuming and requires much larger dust samples than the 20-L chambers.

The PRL 20-L chamber is made of stainless steel, and has a pressure rating of 21 bar. Two optical dust probes (Cashdollar, Liebman & Conti, 1981; Conti, Cashdollar & Liebman, 1982) are used to measure the uniformity of the dust dispersion at the positions shown in Fig. 2. The optical probes measure the transmission through the dust cloud, with path lengths of 38 or 95 mm. The strain gauge pressure transducer measures the explosion pressure and rate of pressure rise (dP/dt). The data from the various instruments are collected by a high speed personal computer (PC) based data acquisition system. The experimental dust concentration reported for the 20-L chamber is the mass of dust divided by the chamber volume. After the dust and ignitor have been placed in the chamber, the chamber is partially evacuated to an absolute pressure of 0.14 bar,a. Then a short blast of dry air (from a reservoir at ~9 bar) disperses the dust and raises the chamber pressure to about 1 bar,a. There is a total ignition delay of ~0.4 s from the start of dispersion until ignition for the standard test procedure in the PRL 20-L chamber. The standard procedure for the Siwek 20-L chamber has an ignition delay of ~0.06 s and a reservoir pressure of 20 bar, resulting in a higher level of turbulence. The usual ignition sources used for the 20-L tests are electrically activated, pyrotechnic ignitors manufactured by Fr. Sobbe[2] of Germany. These ignitors are available in various energies from 250 to 10,000 J.

[2] Mention of any company name or product does not constitute endorsement by NIOSH.

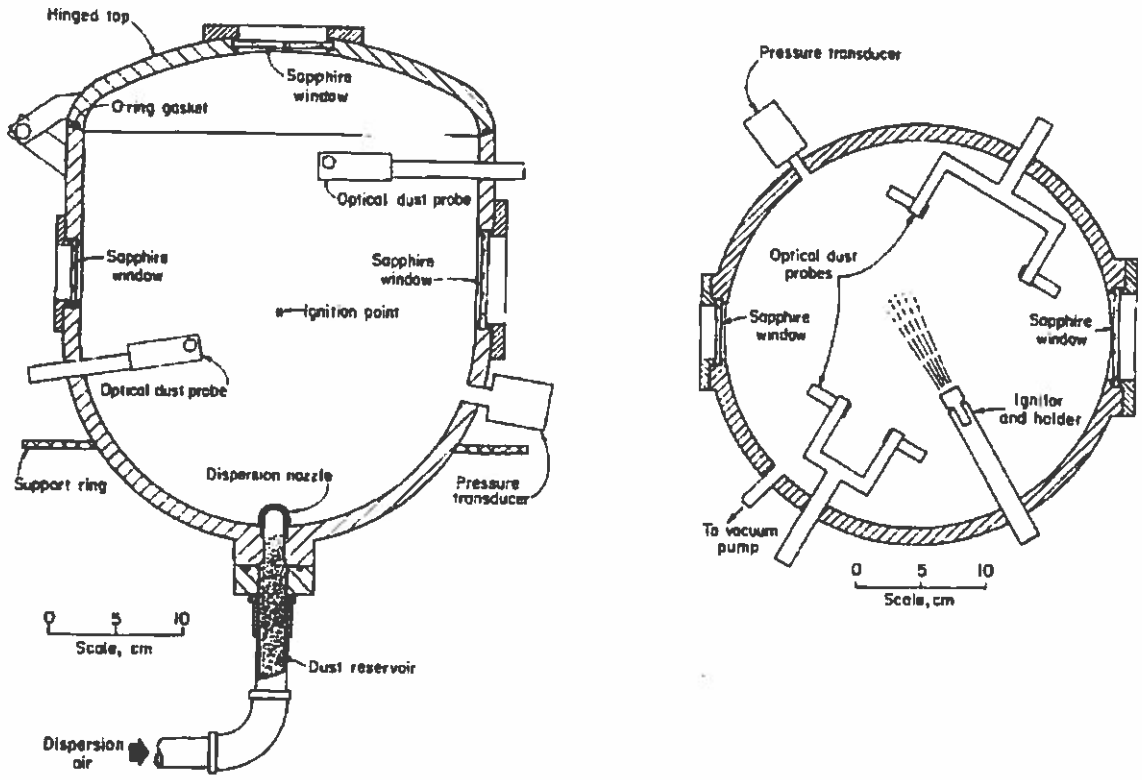

Fig. 2. Vertical and horizontal cross sections of PRL 20-L explosibility test chamber.

The 2500-J ignitor is comparable in energy to an entire book of 20 pocket matches, all ignited at once. The Sobbe ignitors are much stronger than the electric sparks used in the 1.2-L Hartmann tests.

4. Explosion characteristics

4.1. Pressures and rates of pressure rise

Examples of the pressure data for a weak and a moderate coal dust explosion are shown in Figs. 3 and 4. The absolute pressure (Figs. 3A and 4A) and rate of pressure rise (Figs. 3B and 4B) are plotted versus time. Fig. 3 shows the data for a 20-L chamber explosion test of a low volatile bituminous coal at a dust concentration of 125 g/m^3, which is just above the minimum required for an explosion. The pressure trace in Fig. 3A starts at the partially evacuated value of 0.14 bar.a. The blast of air that disperses the dust starts at 0.1 s and ends at 0.4 s on the pressure–time trace. The ignitor is activated at 0.5 s at a chamber pressure of 1.0 bar.a. The maximum explosion pressure is about 3 bar.a or a pressure rise of about 2 bar. In Fig. 3B, the rate of pressure rise,

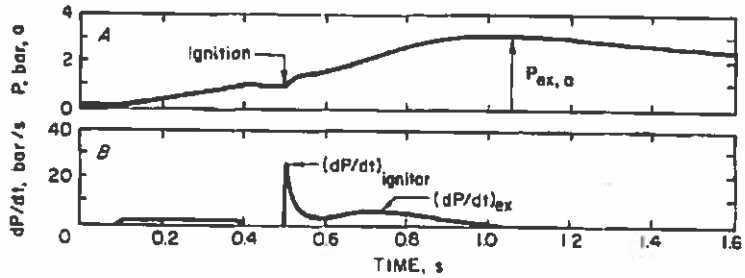

Fig. 3. Typical pressure data for a weak dust explosion.

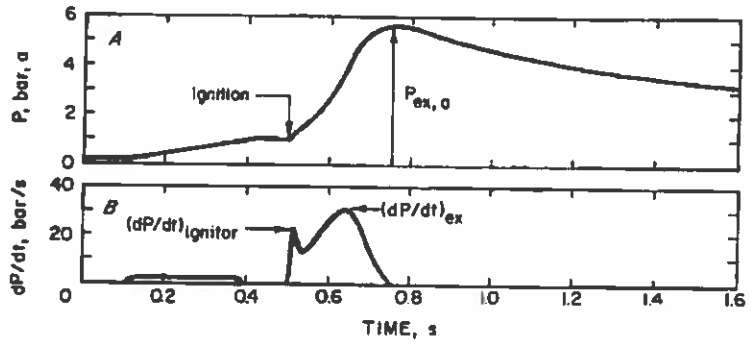

Fig. 4. Typical pressure data for a moderate dust explosion.

$(dP/dt)_{ignitor}$, for the ignitor is larger than $(dP/dt)_{ex}$ for the dust explosion itself. It is important to determine $(dP/dt)_{ex}$ rather than the ignitor effects. Fig. 4 shows data for a larger explosion of the low volatile coal dust at a higher concentration of 200 g/m^3. The maximum explosion pressure is about 5.5 bar,a or a pressure rise of 4.5 bar. For this explosion, the $(dP/dt)_{ex}$ for the dust explosion is greater than $(dP/dt)_{ignitor}$.

Examples of absolute pressure versus time traces for typical dust explosions at a concentration of 600 g/m^3 in the constant volume 20-L chamber are shown in Fig. 5. The traces are for two carbonaceous dusts and six metal dusts. The relative reactivity of the dusts can be estimated from either the peak explosion pressure or the maximum rate of pressure rise. The aluminum (Al) has the highest reactivity, in part because it is much finer in size than any of the other dusts in Fig. 5. Next in order of reactivity is the magnesium (Mg) dust, followed by the two carbonaceous dusts (polyethylene and coal). The polyethylene and the high volatile bituminous coal (hvb) have similar maximum pressures, but the polyethylene has a faster rate of pressure rise. The titanium (Ti) dust has a lower explosion pressure than the carbonaceous dusts, and the iron (Fe) and zinc (Zn) dusts are even lower. The dust with the lowest reactivity in Fig. 5 is the tantalum (Ta) dust, which barely reaches its maximum pressure by 250 ms. The relative reactivities of these dusts are dependent not only on the intrinsic reactivities of the materials but also on the specific particle sizes of the dusts.

The pressure evolution of an explosion in a constant volume system is predicted by classical combustion theory (Lewis & von Elbe, 1961, pp. 367–381). For the ideal case, the absolute pressure as a function of time,

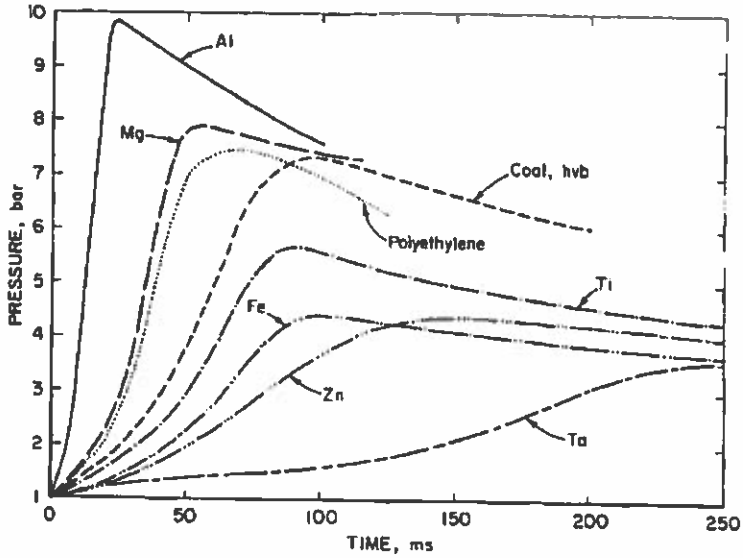

Fig. 5. Explosion pressure traces for carbonaceous and metal dusts.

$P(t)$, in a constant volume, spherical explosion is related to the fractional volume, $V(t)$, occupied by the fireball during the time of propagation, t, as follows (Hertzberg & Cashdollar, 1987):

$$\frac{P(t)-P_0}{P_{max}-P_0}=k\frac{V(t)}{V_0} \tag{3}$$

where P_0 is the initial absolute pressure, V_0 is the chamber volume, and k is a correction factor related to the difference in compressibility between burned and unburned gases. For spherical propagation from a point source,

$$\frac{V(t)}{V_0}=\left[\frac{r(t)}{r_0}\right]^3=\left[\frac{S_b t}{r_0}\right]^3 \tag{4}$$

where $r(t)$ is the fireball radius, r_0 is the chamber radius, and S_b is the flame speed given by:

$$S_b=\frac{dr(t)}{dt}=\left(\frac{\rho_u}{\rho_b}\right)S_u \tag{5}$$

where ρ_u/ρ_b is the density ratio of unburned to burned gases (at constant pressure). The burning velocity, S_u, is the rate of flame propagation relative to the unburned gas ahead of it. The flame speed, S_b, is relative to a fixed reference point. Note that both S_b and S_u are for turbulent not laminar conditions for dust explosions. For spherical propagation in a spherical chamber, the maximum pressure is reached just as the flame contacts the wall. At that instant, $k=1$. Differentiating Eq. (3) with respect to time and substituting Eqs. (4) and (5) into the results gives:

$$\frac{dP(t)}{dt}=3(P_{max}-P_0)\frac{r(t)^2}{r_0^3}\frac{dr(t)}{dt} \tag{6}$$

$$=3(P_{max}-P_0)\left(\frac{\rho_u}{\rho_b}\right)S_u\frac{r(t)^2}{r_0^3}$$

Eq. (6) shows that the maximum rate of pressure rise should also occur at the instant the flame front contacts the wall. Setting $r(t)=r_0=(3V_0/4\pi)^{1/3}$ and letting $\rho_u/\rho_b\approx T_b/T_0\approx P_{max}/P_0$, gives:

$$K_{St}=\left[\frac{dP(t)}{dt}\right]_{max}V_0^{1/3}=4.84\left(\frac{P_{max}}{P_0}-1\right)P_{max}S_u \tag{7}$$

Eq. (7) is the "cubic law", and K_{St} is the size normalized maximum rate of pressure rise.[3] The subscript "St" refers to Staub, the German word for dust. Because it is size normalized, the K_{St} value is used in the practical design of venting systems (NFPA, 1998).

This derivation of the "cubic law" is based on the idealized condition where the vessel size is large compared with either the dust flame thickness or the ignitor flame volume. This may be approximately true in the 1-m³ chambers. However, in the 20-L chambers with pyrotechnic ignitors, it is certainly not true, and the ignition and combustion are more volumetric (Zhen & Leuckel, 1997).

4.2. Dust concentration effects

In order to study the overall explosibility characteristics of a dust, tests must be made over a range of concentrations to determine the "worst case". Explosibility data for the high volatile Pittsburgh bituminous coal dust are shown in Fig. 6 as a function of dust concentration. At the top of the figure, the transmission data measured by the optical dust probes are shown. The transmission is measured over a 0.1-s time interval just before the dust is ignited. As described in Cashdollar et al. (1981) and Conti et al. (1982), the transmission τ is related to the mass concentration C_m by Bouguer's law: $\tau=\exp(-3QC_m\ell/2\rho D_s)$, where Q is a dimensionless

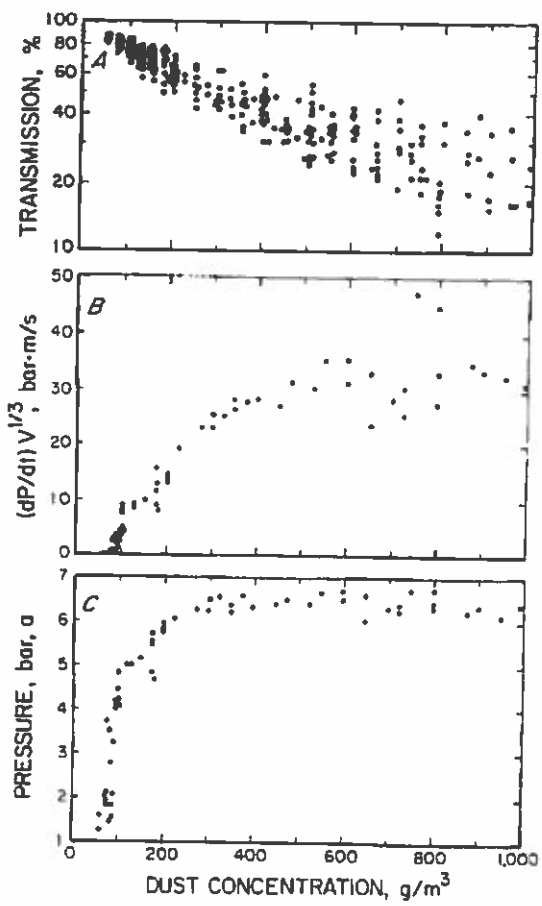

Fig. 6. Explosibility data for high volatile bituminous coal dust.

[3] Note that this equation has been corrected from the version in eq. (7) in Hertzberg & Cashdollar (1987).

extinction coefficient, ℓ is the path length, ρ is the density of a particle, and $\bar{D}_s$ is the surface mean particle diameter. The data in Fig. 6A generally follow the expected linear relationship on this semi-logarithmic plot. At the highest dust concentrations, there is some upward curvature, probably due to increased agglomeration. The scatter in the data is probably due to variations in the agglomerated particle size of the air dispersed dust.

In Fig. 6B, $(dP/dt)V^{1/3}$ is the volume normalized maximum rate of pressure rise. Note that the turbulence level was lower in the PRL 20-L chamber for these tests than that recommended in ASTM E1226 (ASTM, 1999a). Therefore, the $(dP/dt)V^{1/3}$ data in Fig. 6B are not recommended for the sizing of vents according to ISO Standard 6184/1 (ISO, 1985), NFPA Guide 68 (NFPA, 1998), and VDI Standard 3673 (VDI, 1983). These consensus standards are based on the higher turbulence level of the Siwek 20-L chamber and the 1-m^3 chamber (Bartknecht 1981, 1989). These PRL 20-L data are, however, useful as a relative measure of explosion hazard. At the higher turbulence level recommended in ASTM Standard E1226, the maximum $(dP/dt)V^{1/3}$ data for this Pittsburgh coal would be roughly three times higher. The maximum absolute explosion pressures (with the pressure rise of the ignitor subtracted) are shown in Fig. 6C. Because there are small variations from test to test in the chamber pressure at the time of ignition, these data were normalized to a starting pressure of 1.0 bar,a. The data in Fig. 6 show that below a certain dust concentration, explosions are not observed. This is the minimum explosible concentration (MEC) or lean flammable limit (LFL). For this coal, the measured MEC in the 20-L chamber is ~80 g/m^3. This is the same as the ~80 g/m^3 MEC-value measured for the same coal in a 1-m^3 chamber using a 10-kJ ignitor (Cashdollar & Chatrathi, 1993; Cashdollar, Weiss, Greninger & Chatrathi, 1992). At higher dust concentrations in Fig. 6, the maximum pressures and rates of pressure rise level off as all of the oxygen in the chamber is consumed, but there is no evidence of a rich limit for the coal dust. Typical of dusts, there is more scatter in the rate of pressure rise data than in the pressure data.

A summary of the 20-L chamber pressure versus concentration data for the bituminous coal and polyethylene dusts is shown in Fig. 7, where the data are compared with those for methane (CH_4) gas. The data for the two carbonaceous dusts are similar, except that the polyethylene has a lower MEC and a slightly higher maximum explosion pressure. This is because the polyethylene has a volatility of 100% compared with 37% volatility for the coal, and it has a higher H:C ratio than the coal. The methane gas has a LFL or MEC similar to that of the polyethylene. This shows that the completely volatilizable polyethylene reacts similarly to the methane gas at low concentrations (Hertzberg et al., 1988b). For

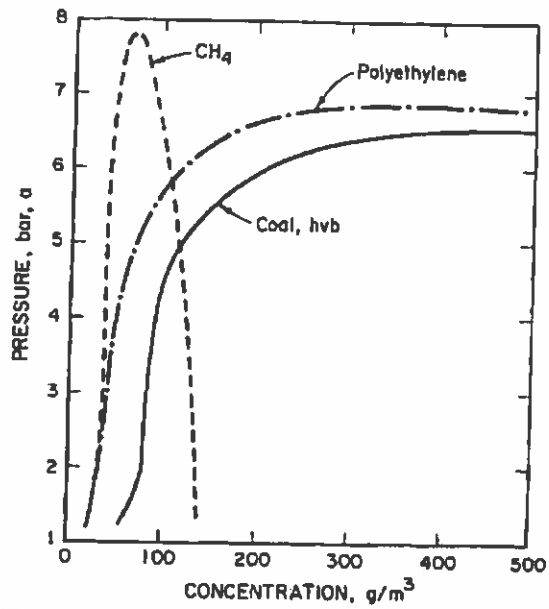

Fig. 7. Explosion pressure data for high volatile bituminous (hvb) coal and polyethylene dusts, compared with those of methane gas.

hydrocarbon gases or dusts, the measured LFL or MEC generally corresponds to a calculated adiabatic temperature (Hertzberg et al., 1988b) of 1300 to 1500 K. This is the "limit flame temperature", which is the minimum temperature needed to keep a flame propagating. Experimentally, the LFLs of most hydrocarbon gases are easy to measure because the gases have low ignition energies. Much stronger ignition energies are needed for dusts (Cashdollar & Chatrathi, 1993; Hertzberg, Cashdollar & Zlochower, 1988a). However, if too strong an ignition energy is used relative to the test chamber volume, the result will be an overdriven ignition (Cashdollar & Chatrathi, 1993). A standard method for measuring the MEC of a dust cloud is ASTM E1515 (ASTM, 1999b).

In contrast to the two dusts in Fig. 7, the methane gas shows a rich limit. For the dusts, the maximum pressures level off at concentrations of 200 to 300 g/m^3 as all of the oxygen in the chamber is consumed. At even higher dust concentrations, although the mixtures are nominally fuel rich, the pressure nevertheless remains constant. The normal rich limit observed for hydrocarbon gases such as CH_4 is not observed for the dusts. An explanation of this effect, at least for many dusts, is that the solid phase fuel must first devolatilize before it can mix with the air (Hertzberg et al., 1988b). As soon as sufficient volatiles are generated to form a stoichiometric concentration of volatiles in air, the flame front propagates rapidly through the mixture before excess fuel volatiles can be generated.

Fig. 8 shows explosibility data from the 20-L chamber

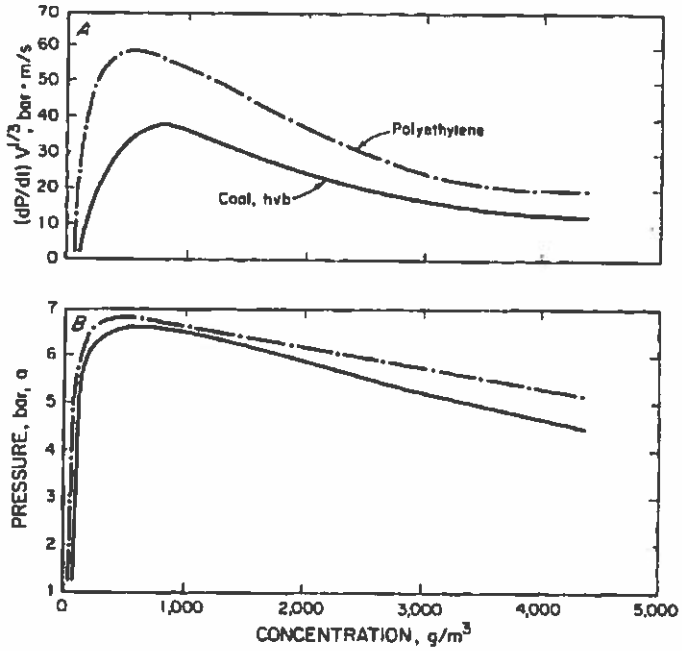

Fig. 8. Explosibility data at very high dust concentrations for high volatile bituminous coal and polyethylene dusts.

with 2500-J ignitors for the high volatile coal dust and for polyethylene dust at very high concentrations. This shows that these dusts explode even at concentrations beyond 4000 g/m^3. There is, of course, an increased uncertainty in the dust dispersion effectiveness at these very high concentrations. The decrease in pressure at higher concentrations may be due to the increased heat sink of the very large dust concentrations. The decrease in dP/dt at higher concentrations may be due to the increased heat sink effect and/or to the possible decrease in turbulence due to the large mass of dust. Deguigand & Galant (1981) had previously observed an apparent upper limit at ~4 kg/m^3 for coal dust, but this may have been only an ignitability limit because they used an electric spark ignition source that was much weaker than the 2500-J Sobbe ignitor used here. Mintz (1993) observed some upper limits under conditions of reduced oxygen and at large coal particle sizes. In principle, there are rich limits for dusts. Eventually, the large mass of excess fuel will become too much of a heat sink and the flame temperature will be reduced below its limit value. However, for most practical purposes, dusts can be considered to have no rich limit of explosibility. This observation has also been made by Wolanski (1992).

Examples of scanning electron microscope (SEM) photomicrographs of coal before and after explosions are shown in Fig. 9. The dust was a narrow size distribution of Pittsburgh coal with a mass median diameter, $D_{med} \approx 23$ μm. The original unburned particles are shown at two magnifications on the left side of the figure. They are compared to the "burned" post-explosion particles in the four frames on the right side of the figure. The burned particles are mainly char residues that are often larger than the original particles. In the flame, the bituminous coal particles become molten as shown by the rounded particles on the right. Some particles form cenospheres. The particles also devolatilize in the flame, and the volatiles are emitted through the "blow holes" seen in the char residues. Additional SEM photomicrographs for various post-explosion dust residues are in Ng, Cashdollar, Hertzberg & Lazzara (1983).

Metal dusts show similar explosibility data to carbonaceous dusts, as shown by the data for two sizes of iron dust in Fig. 10. The Fe-1 dust was finer in size and had $D_{med} \approx 4$ μm; the Fe-2 dust had $D_{med} \approx 45$ μm. The explosion pressures, rates of pressure rise, and measured explosion temperatures are shown as a function of dust concentration. Fig. 10C shows the measured explosion pressure (absolute) for each test, corrected for the pressure rise due to the ignitor. Fig. 10B shows the size normalized maximum rate of pressure rise, $(dP/dt)V^{1/3}$, for each explosion test. As for the coal dust data in Fig. 6, the iron data in Fig. 10 show that explosions are not observed below a certain dust concentration. The MECs for the Fe-1 and Fe-2 dusts are about 220 and 500 g/m^3, respectively, based on the procedures of ASTM E1515 (ASTM, 1999b). However, there is considerable uncertainty in these values, especially for the Fe-2 dust, due

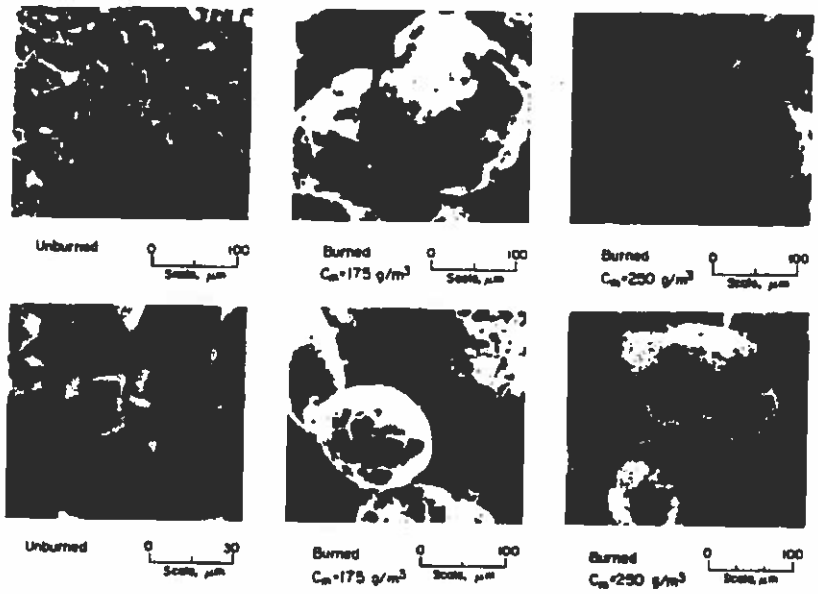

Fig. 9. Scanning electron microscope photographs of bituminous coal particles before and after explosions.

to the scatter in the data. At the higher dust concentrations, P_{max} and $(dP/dt)_{max}V^{1/3}$ level off as all of the oxygen in the chamber is consumed. Similar to the carbonaceous dusts in Fig. 8, the iron metal dusts show no evidence of a "normal" rich limit.

The explosion temperatures shown in Fig. 10A were measured with a six-wavelength infrared pyrometer (Cashdollar & Hertzberg, 1982). The pyrometer observed the continuum radiation from the particles, and temperatures were calculated from the best Planck curve fit to the infrared radiance data. The maximum measured particle temperatures for the Fe-1 dust were ~1800 K, well below the maximum calculated adiabatic temperature, $T_{ad,max}$=2250 K, for ideal combustion at constant pressure (Cashdollar, 1994). The maximum measured particle temperatures for the Fe-2 dust were even lower. These experimental temperatures are only those of the particles in the explosion; the gas temperatures may be different. For all three explosion characteristics shown in Fig. 10, the Fe-1 dust has higher values than the Fe-2 dust, showing that it is more reactive, due to its finer particle size.

4.3. Particle size effects

Most of the previous explosibility data were measured using rather broad size distributions of the dusts. Fig. 11 shows explosibility data from the 20-L chamber for Pittsburgh bituminous coal dust as a function of mass median particle diameter. The data for the narrow size distributions are shown as the solid circles and solid curve. These data for narrow distributions are compared with the data crosses for the broad size distributions of coal dusts. The MEC-values in the bottom section of the figure are relatively independent of particle size for the finer sizes. At the larger sizes, above 100 μm, the MEC-values increase with particle size until a size is reached that can not be ignited. The top two sections of Fig. 11 show that the maximum pressures and rates of pressure rise are found at the finest sizes tested, as expected. The pressures decline slowly and the pressure rise rates decrease faster with increasing particle size. At some size between 200 and 300 μm, the narrow sizes of Pittsburgh coal dust can no longer be ignited. These data are typical for narrow size distributions of carbonaceous fuel dusts. A broad size distribution is just a combination of narrow distributions, and these data show that it is the finer particles in a broad distribution that contribute the most to its hazard. The MEC data crosses for the broad size distributions show little difference from the narrow size distribution data below D_{med}=100 μm. However, the broad size distributions ignite and propagate at larger D_{med} sizes than the narrow size distributions. The pressure and dP/dt data for the broad size distributions are somewhat higher than those for the narrow size distributions, even in the D_{med} range of 20–100 μm. These effects are probably due to the tail of fine particles in the broad size distributions. These fine particles were removed from the narrow size distributions. The main conclusion of Fig. 11 is that particle size has an important effect on the explosibility of coal dusts and other carbonaceous dusts.

Data showing the effect of particle size for iron dust are shown in Fig. 12. Because the size distributions were

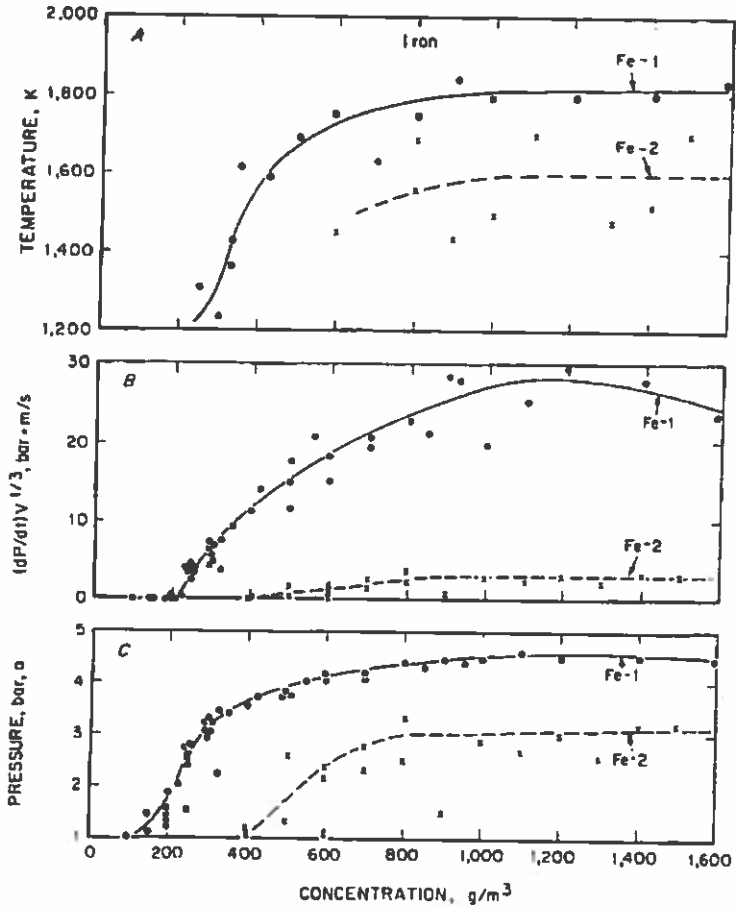

Fig. 10. Explosibility data for two sizes of iron dust

broader and the D_{med} values less certain, the data are shown as bars rather than points. The explosion data are similar to those for the coal dust. The maximum values for pressure and rate of pressure rise are found at the finest particle size. The MEC values are relatively size-independent at the finer sizes and increase above 30 μm until a size is reached that can not be ignited. Additional data for size effects of aluminum dusts are in Cashdollar (1994).

4.4. *Effects of oxygen concentration*

One of the ways to prevent a dust explosion is to inert the atmosphere so that there is insufficient oxygen for a flame to propagate. This removes one side of the fire triangle or explosion pentagon, thereby preventing combustion. One of the most common inerting gases is nitrogen, which is the main constituent of air. To determine the limiting oxygen concentration for coal dust explosions in the 20-L chamber (with 2500-J ignitors), the dusts were dispersed with various oxygen–nitrogen mixtures instead of normal air at 20.95% O_2. Fig. 13 is an example of the reduced oxygen data for coal dust. The explosions are denoted by the solid circles and the nonexplosions by the open circles. The data for coal dust in air are shown at the top of the figure. In air, the dust ignites and burns at all coal concentrations above the MEC of ~80 g/m³. At the bottom of the figure, explosions still occur at 14% down to 11.5% O_2. At 11% O_2, the coal dust ignited only in one out of eight tests. At even lower oxygen concentrations, the dust could not be ignited. The boundary between oxygen concentrations that support combustion and those that do not support combustion is the limiting oxygen concentration, LOC. As a safe margin, NFPA 69 (NFPA, 1997) recommends keeping the system oxygen concentration at least 2% lower than the measured LOC. Gases other than nitrogen can also be used to reduce the oxygen concentration. Carbon dioxide is usually more efficient than nitrogen for inerting carbonaceous dusts, but it is often less effec-

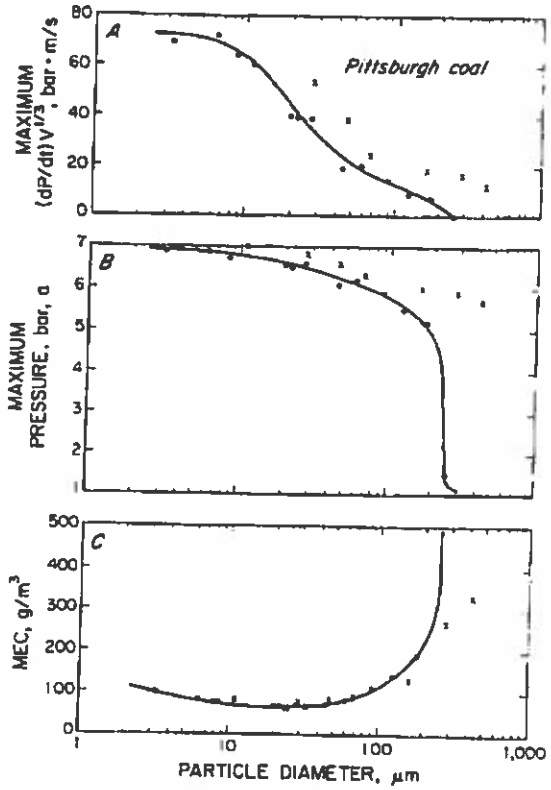

Fig. 11. Effect of particle size on the explosibility of coal dusts: ●, for narrow distributions; ×, for broad distributions.

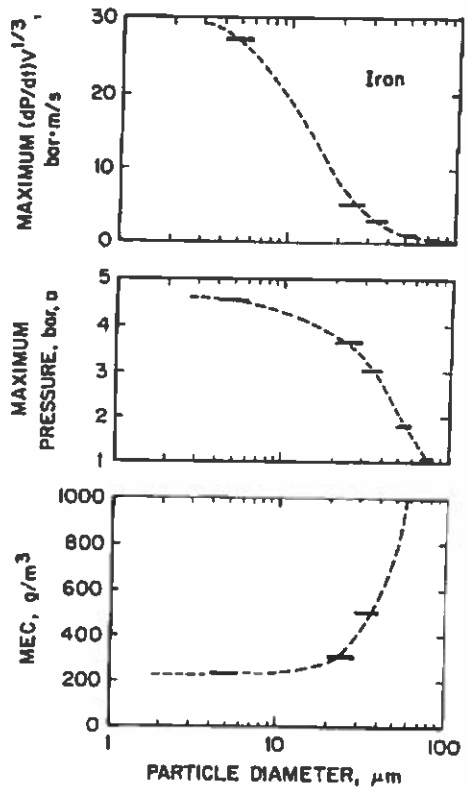

Fig. 12. Effect of particle size on the explosibility of iron dusts.

tive than nitrogen in inerting metal dusts (Nagy, Dorsett & Jacobson, 1964).

The oxidant for a dust explosion is usually the oxygen in air, although other gases can also be oxidizers. Oxygen concentrations greater than 21% tend to increase the burning velocity, and concentrations less than 21% reduce the burning velocity. An example of the effect of varying oxygen concentration on the explosion pressure and rate of pressure rise for a carbonaceous dust is shown in Fig. 14. The data are from DiPalma (1998). The solid data symbols are at a dust concentration of 500 g/m^3 and the open circle data symbols are at a dust concentration of 375 g/m^3. Fig. 14A shows that the rate of pressure rise varies almost exponentially with oxygen concentration on this semi-logarithmic plot. The explosion pressure in Fig. 14B varies roughly linearly with oxygen concentration, although there is some scatter in the data. If the dust concentration was varied at each oxygen concentration to obtain the highest P_{max} value, the explosion pressure would be expected to increase linearly with oxygen concentration, based on the ideal gas law (Eq. (1)). However, this linear relationship would change as the LOC is approached. Near the LOC, the pressure would decrease very rapidly with decreasing oxygen concentration, until the mixture would no longer be explosible.

Because of the large effect of varying oxygen concentration on the explosion characteristics of dusts, it is important to test the dust at the appropriate O_2 concentration. When determining the explosion characteristics for a dust in air, it is important to measure the O_2 content of the "air" cylinders used for the tests. Gas cylinders that are filled with air that has been compressed and dried have the normal 20.95% O_2. However, many "air" cylinders are filled with synthetic or reconstituted "air" that has been mixed from liquified oxygen and nitrogen. The O_2 content of these cylinders has been observed to vary considerably—from 19% to 26% O_2.

4.5. *Effect of temperature*

The thermal ignitability of coal dust is shown in Fig. 15, as measured in the PRL 6.8-L furnace (Conti, Cashdollar & Thomas, 1993). The tests resulting in ignitions (solid circles) and non-ignitions (open circles) are plotted on a graph of initial furnace temperature versus dust cloud concentration. The solid curve is the temperature boundary between the upper region of the graph where

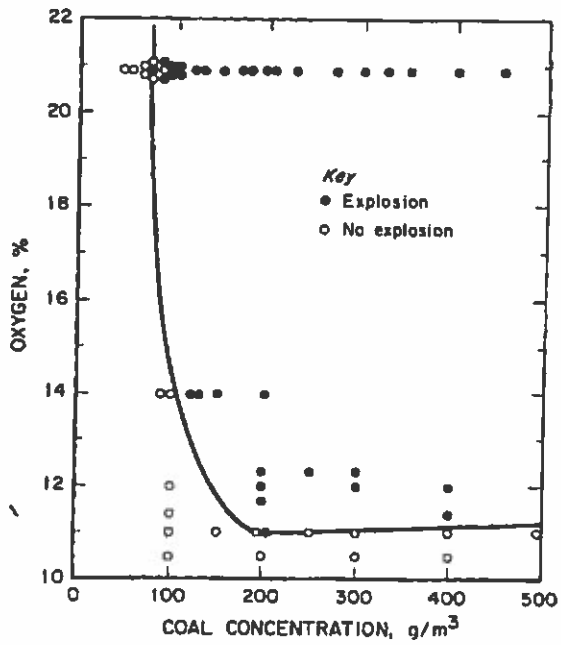

Fig. 13. Effect of reduced oxygen concentration on coal dust explosibility

the coal dust cloud will thermally autoignite and the lower region where the dust may be flammable but does not thermally autoignite. The lowest point of the curve is the minimum autoignition temperature (MAIT) for the coal—530°C. This 6.8-L furnace is one of several listed in ASTM standard test E1491 for the measurement of the MAIT's of dusts (ASTM, 1999c).

The effect of temperature on the ignitability and explosibility of coal dust is shown in Fig. 16. The dotted curve (from Fig. 15) shows the autoignition temperature for the coal as a function of dust concentration. The dotted curve is the temperature boundary between the upper region of the graph where the coal dust cloud will thermally autoignite and the lower region where the dust may be flammable but does not thermally autoignite. In addition to the 6.8-L furnace data, explosibility tests were also conducted in the 20-L chamber at temperatures above ambient but below the temperature at which the dust would autoignite. For these tests, the 20-L chamber was wrapped with electrical heater tape and insulated to reach the elevated temperature. A thermocouple measured the set temperature of the chamber before the test. The solid circle data points in Fig. 16 show the MEC-data (Cashdollar, 1996) for the coal dust at near ambient (~60°C) and at an elevated temperature of ~180°C. The experimental data points are extrapolated to even higher temperatures (solid curve) using the modified Burgess–Wheeler law (Zabetakis, 1965; Conti, Cashdollar, Hertzberg & Liebman, 1983) for hydrocarbons:

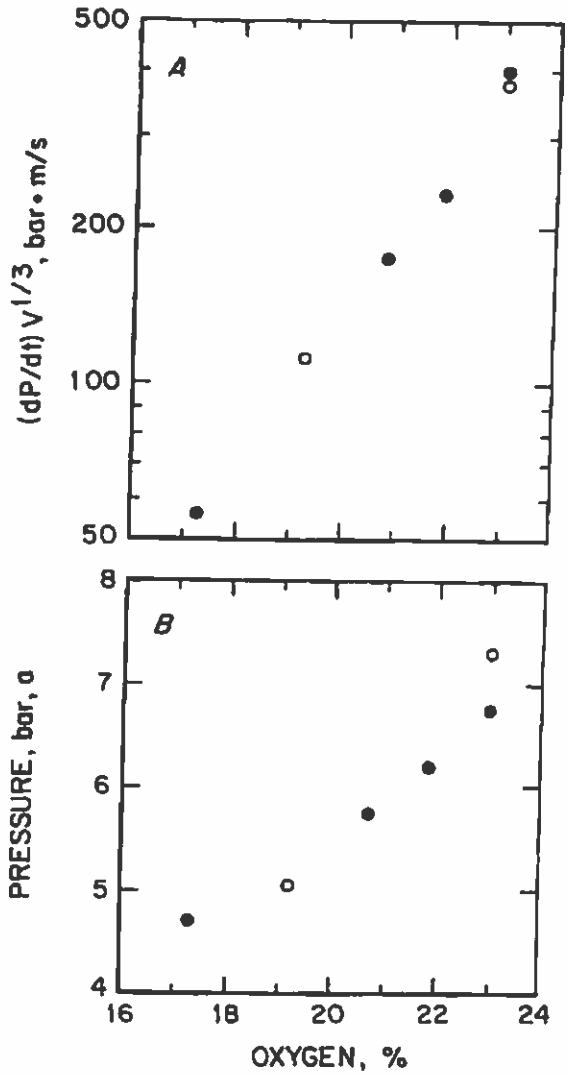

Fig. 14. Effect of oxygen concentration on explosion pressures and rates of pressure rise (data from DiPalma, 1998).

$$C_T = C_{T_0}\left(\frac{273+T_0}{273+T}\right)[1-0.00072(T-T_0)] \quad (8)$$

where C_T is the limit in terms of mass concentration at temperature T, C_{T_0} is the limit at T_0, and the temperatures are in °C. The dust concentrations to the right of the solid curve are flammable (explosible) and the region to the left of the curve is nonflammable. For comparison, the measured lean flammable limit data for methane gas as a function of temperature (dashed curve, from Coward & Jones, 1952, p. 43) are also shown. The decrease in the LFL or MEC with increase in temperature is similar in form for the dust and gas.

At higher dust concentrations, the maximum

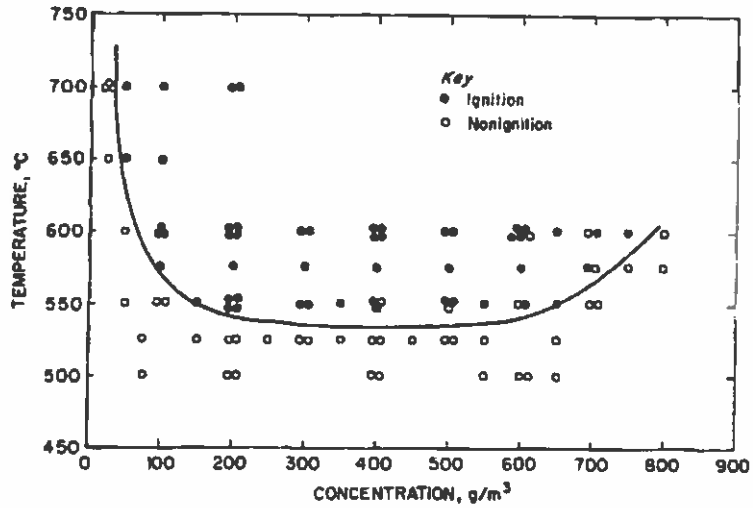

Fig. 15. Thermal ignitability of coal dust.

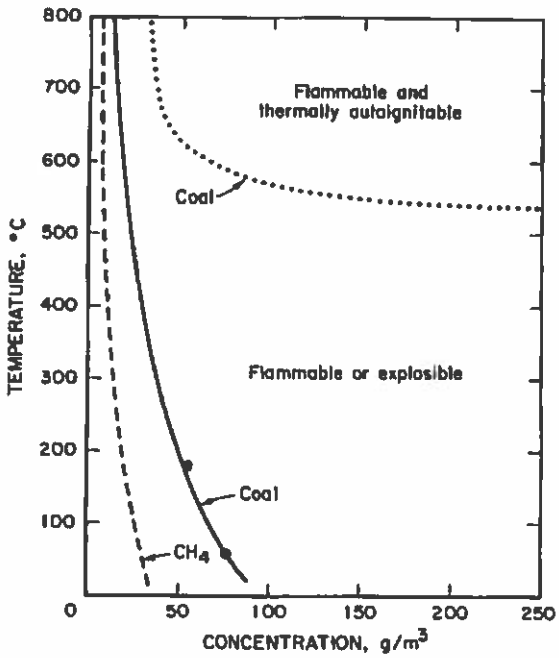

Fig. 16. Effect of temperature on the flammability and thermal ignitability of coal, compared with methane gas.

explosion pressure for the bituminous coal was also measured at elevated temperature in the 20-L chamber (Cashdollar, 1996). At near ambient temperature, P_{max} for the dust was 6.6 bar.a. At an elevated temperature of ~180°C, P_{max} was 4.8 bar.a. This observation of lower explosion pressures at elevated temperature was also reported previously by Wiemann (1987). The inverse relationship of explosion pressure with initial temperature is expected from the ideal gas law (Eq. (1)) because there are fewer oxygen molecules at elevated temperature to react with the coal. The ratio of measured maximum explosion pressure (absolute) at elevated temperature to that at ambient temperature is approximately the same as the ratio of ambient to elevated temperature in degrees kelvin.

The limiting oxygen concentration for coal dust was also measured at elevated temperature in the 20-L chamber. The measured LOC value (Cashdollar, 1996) for the dust decreased from ~11% at ambient temperature to ~10% at ~180°C. This effect of lower LOC values at elevated temperature was also observed previously by Wiemann (1987).

4.6. *Effect of pressure*

The effect of initial chamber pressure (Hertzberg et al., 1988a) on the MEC or LFL of gases and dusts is shown in Fig. 17. When the methane concentration is expressed in volume percent in Fig. 17A, the LFL is shown to be constant as the pressure varies from 0.5 to 3 bar. When the CH_4 is expressed in mass concentration in Fig. 17B, the LFL is shown to vary linearly with pressure. In Fig. 17C, the LFLs of the Pittsburgh coal and polyethylene dusts also vary linearly with pressure. A similar relationship was found by Wiemann (1987) for a brown coal dust.

Bartknecht (1989) and Wiemann (1987) report data on the effect of initial pressure on the P_{max} and K_{St} values. Both show that P_{max} increases linearly with increase in initial pressure, over the range of 1–4 bar. They also show that K_{St} increases with initial pressure.

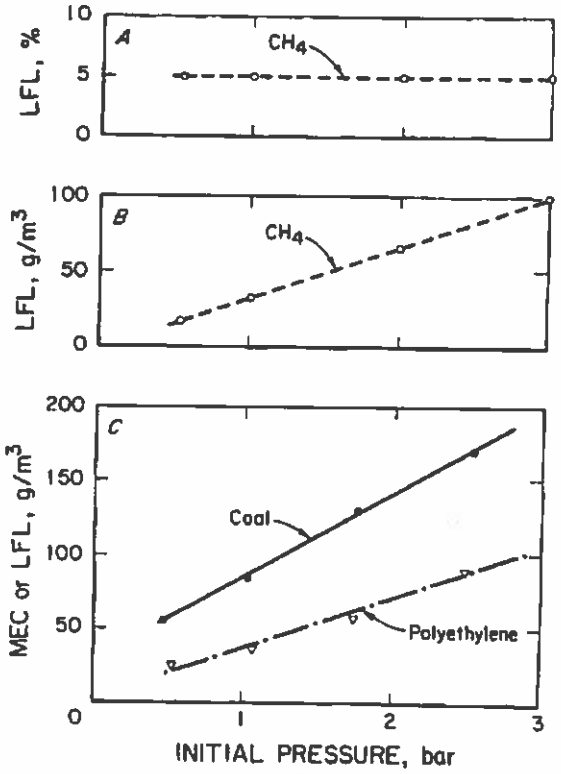

Fig. 17. Effect of pressure on the lower flammable limits for coal and polyethylene dusts, compared with methane gas.

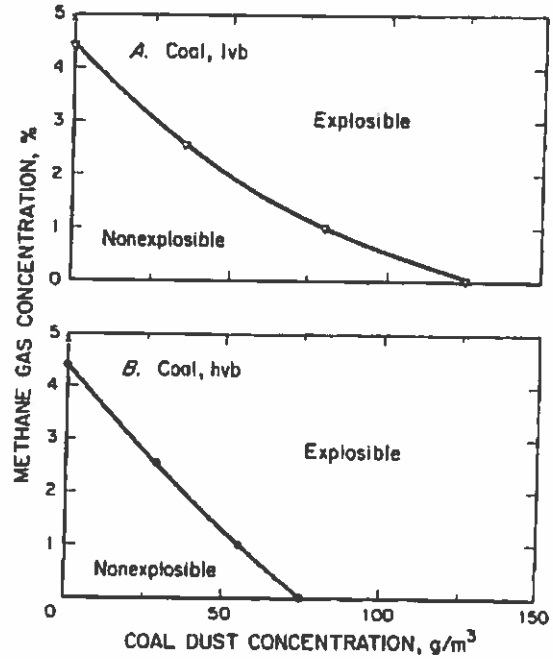

Fig. 18. Lower flammable limits for hybrid mixtures of low and high volatile coal dusts with methane gas.

4.7. *Hybrid mixtures of dusts and gases*

Another important factor in the explosibility hazard of a dust is the possible co-presence of a flammable gas. Hybrid mixtures of a combustible dust (coal) and a flammable gas (CH_4) were also studied in the 20-L chamber using 2500-J ignitors (Cashdollar, 1996). Data for a low volatile bituminous (lvb) coal are shown in Fig. 18A, and for a high volatile bituminous (hvb) coal in Fig. 18B. The flammable limits for mixtures of coal and CH_4 are shown by the data points and solid curves. The areas above and to the right of the curves are explosible (flammable) and the areas below and to the left of the curves are nonexplosible (nonflammable). The data for mixtures of Pittsburgh coal and CH_4 in Fig. 18B show a linear or near-linear mixing relationship similar to Le Chatelier's Law for hydrocarbon gases (Zabetakis, 1965; Kuchta, 1985, pp. 48–50). All of the solid circle data symbols are for 2500-J ignitors. The measured LFL for the pure CH_4 with this 2500-J ignitor is 4.4%, but this is an overdriven system as shown by tests in a larger 120-L chamber (Hertzberg et al., 1988a). The more appropriate LFL for CH_4 is the 4.9% value measured with a 1000-J ignitor in the 20-L chamber and shown as the symbol × in the figure. The data for hybrid mixtures of the low volatile Pocahontas coal and CH_4 in Fig. 18A show some curvature. This is probably due to the even greater difference in ignitability between the low volatile coal and the CH_4. That is, the dust becomes more easily ignited as more CH_4 is added. Therefore, the curvature is more likely an effect of ignitability rather than an effect of flammability. Ideally, the true mixing relationship would be determined in a much larger chamber, such as a 1-m^3 chamber, where a very strong ignition source could be used for the dusts without overdriving the CH_4 gas. For most practical situations for mixtures of hydrocarbon dusts and gases, the linear mixing law of Le Chatelier would be sufficient. This approximately linear relationship for the lean limits of coal dust and CH_4 gas mixtures was also observed by Amyotte and colleagues (Amyotte, Mintz, Pegg, Sun & Wilkie, 1991; Amyotte, Mintz, Pegg & Sun, 1993) using 5000-J ignitors in a 26-L chamber. This linear mixing relationship is also applicable to mixtures of two carbonaceous dusts (Hertzberg & Cashdollar, 1987). However, it is not applicable to mixtures where the two components have greatly different limit flame temperatures, such as a carbonaceous dust and hydrogen gas (Hertzberg & Cashdollar, 1987).

4.8. Effect of added inert dust

The addition of an inert powder to a combustible dust and air mixture can reduce the explosibility through the absorption of heat. In the mining industry, coal dust explosions are prevented by the addition of limestone rock dust to the deposited coal dust (Nagy, 1981). Since the limestone is incombustible, it acts as a heat sink to reduce the flame temperature of the dust mixture below its limit value. The inerting of coal dust by the addition of limestone rock dust has been studied in the PRL 20-L laboratory chamber, and the results were compared to those from full-scale experimental mine tests (Cashdollar et al., 1992; Cashdollar, 1996; Cashdollar & Hertzberg, 1989; Greninger et al., 1991). The laboratory data are shown in Fig. 19. In the top part of the figure, the LFL or MEC of the coal dust shows almost no effect with added rock dust until there is over 50% rock dust in the mixture. At higher rock dust percentages, the LFL increases, until the mixture can not be ignited at ≥75% rock dust. The two lower parts of the figure show the maximum pressure and rate of pressure rise as a function of rock dust percentage in the mixture. At each rock dust percentage, the coal dust concentration was varied over a series of tests to determine the maximum pressure and dP/dt. The explosion pressures show only a slight decrease with added rock dust content up about 70%. Between 70% and 80% rock dust, the pressures drop rapidly as the mixture becomes totally inerted and flame no longer can propagate. The rates of pressure rise decline almost linearly with increased rock dust content over the entire range. The 20-L laboratory data for the rock dust inerting of coals shows relatively good agreement with large-scale data from the PRL experimental mine (Cashdollar et al., 1992; Greninger et al., 1991; Weiss et al., 1989). Therefore, the laboratory chamber can be used for preliminary testing to reduce the number of large-scale tests. The mining regulations are still based on the results of the large-scale research.

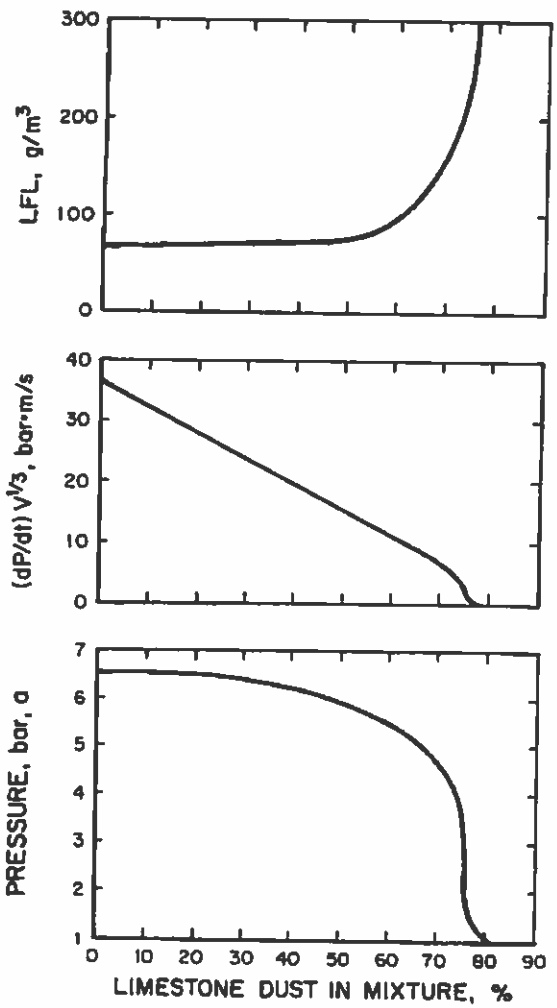

Fig. 19. Effect of added inert dust on the explosion characteristics of bituminous coal dust.

In addition to the use of inert powders premixed with the combustible dust in order to prevent ignition and flame propagation, inert powders are also used in suppression systems to extinguish propagating explosions.

5. Conclusions

The data examples reported in this paper show that laboratory test chambers are useful in studying a wide range of explosion characteristics of dusts. For both carbonaceous and metal dusts, the finer sized dusts are the more hazardous. Because of the importance of particle size, it is critical that representative samples of dusts be collected for explosibility evaluation. Because of the possible accumulation of fines at some location in a processing system, ASTM E1226 (ASTM, 1999a) and E1515 (ASTM, 1999b) recommend that the test sample be less than 200 mesh. It is also important to consider the effects of the initial system temperature, pressure, and oxygen concentration on the explosion characteristics.

Acknowledgements

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explosions and helping him to understand combustion theory.

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