BOILER FURNACE IMPLOSIONS

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1.0 SCOPE

This data sheet discusses the prevention of implosions associated with boiler furnaces. It describes the problems encountered with the fuel burning system, air supply/gas removal system, and the interlocks and alarms built into the control system.

1.1 Changes

January 2002. Clarification was made in section C.1.3.1.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

The following recommendations are directed primarily towards new units. Since older units are also subject to implosion, these should be carefully examined to determine what course of action should be taken for their particular cases, depending upon its age, condition, type of use, etc. In some cases, it may be feasible to upgrade the structural supports and not add the extra control devices or vice versa (e.g., a small unit with a small ID fan capable of relatively low head within structural design limitations).

For example, if a scrubber is being added to an older unit and additional fans are being installed for the scrubber, upgrading of the furnace may be necessary. Also, if ID fans are being added to units previously operated as pressurized units, or if ID fans are just being rebuilt, upgrading will be necessary. These are just a few examples.

There are many variables which must be considered in determining upgrading of boiler furnaces to meet pressure requirements on both old and new units. The following is a list of general recommendations that should be implemented when contemplating an upgrading of a particular unit, or when choosing a new unit to be installed. By following these recommendations, the chances of having an explosion will not increase. In most cases, they will help to guard against both explosion and implosion.

2.2 Equipment and Processes

2.2.1 Construct the furnace to be capable of holding an internal pressure of ±35 in. of water (±8.7 kPa, 87 mbar), or to withstand the test block capability of the ID or FD fans, whichever is less, without permanently deforming any part of the furnace.

2.2.2 Maintain the furnace pressure between the limits suggested by the manufacturers using furnace pressure control equipment.

2.2.3 Provide three furnace pressure transmitters, each connected to the furnace on its own tap, to provide a cross-referencing for the control equipment to avoid problems caused by faulty measurements from malfunctioning equipment.

2.2.4 Provide a boiler air flow demand signal initiated from an interrelated system (fuel flow, boiler master or other index of demand) other than the measured air flow signal.

2.2.5 Set up controlling equipment to avoid major draft excursions during MFT's and to act within the limits of associated equipment timing.

2.2.6 Make provision for backup power sources to be connected to all devices associated with furnace pressure controlling equipment.

2.2.7 Adjust all interlocking and controlling equipment settings, such as furnace pressure, time delays, main fuel trips, etc. according to manufacturer's recommendations. For example, furnace pressure settings could be set to alarm at ±4 in. w.c. (0.995 kPa, 10 mbar) and trip the unit at ±7 in. w.c. (1.6 kPa, 0.016 bar). These figures are illustrative and not to be used as firm recommendations. They are rough figures to give an idea of the range to look for.

2.2.8 If scrubbers are to be added, it is best to have them provided with a bypass and dampers so that during emergencies, the dampers to the scrubbers can divert the flow to the stack and isolate the booster fans. This procedure would cut down on the total head capability of the system during excursions.

2.2.9 Set up all draft controlling equipment so that if it fails, it will fail in the status quo or safe mode. Other associated equipment that interfaces with the draft controlling equipment should be sensitive to conditions affecting the draft controllers so that it may also react properly during transient conditions.

2.3 Operation and Maintenance

2.3.1 Make and record regular maintenance checks on all draft controlling equipment to ensure that all equipment is functioning properly and free of any restrictions.

2.3.2 Check all new draft controlling equipment and new installations to ensure that they are installed according to manufacturer's recommendations. This includes alignment, positioning, etc., which could lead to failures.

2.3.3 Implement all recommended practices mentioned in Section C.1.3.2, Interlocks and Alarms, and explained in the paragraphs associated with Figure 3. Section C.1.3.2 includes recommended practices for high furnace pressure and draft, loss of all FD fans, and loss of all ID fans.

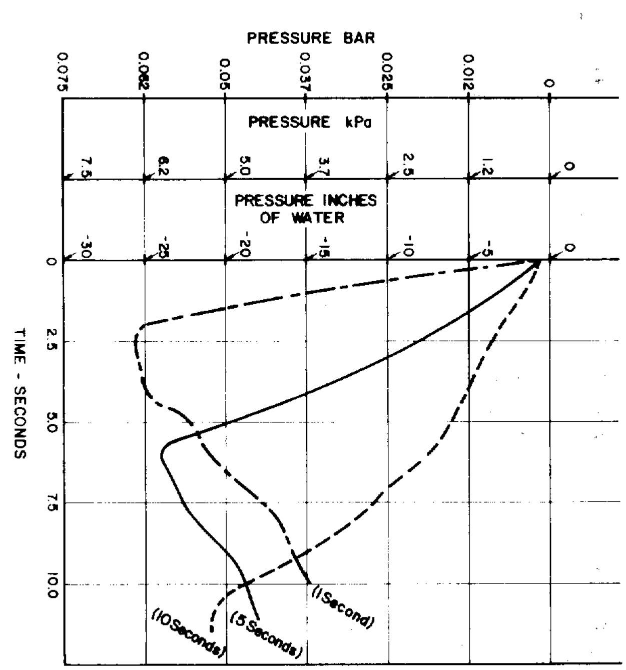
2.4 Training

2.4.1 Provide proper training for all operators to ensure that they are well versed in implosion prevention methods. Train all operators in the operation of their unit and how to act in emergency situations. This can be done by proper instruction at the plant site by qualified operators or instructors and/or manufacturer's representatives.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Background Information

The following information was used in reaching some conclusions discussed in this data sheet.



Note: Curves represent furnace pressure following an MFT from 100% load for various fuel shutoff times labelled on curve.

Fig. 1. Furnace draft vs. time after MFT.

Figure 1 represents furnace pressure vs time after an MFT. Each of the curves on the graph represents a different shutoff time for the fuel. In each case, maximum negative furnace pressure is reached within two seconds after all of the fuel is shut off. In the case of the 10 second fuel shutoff time, maximum negative pressure is reached at the 11 second mark. The fuel is gradually withdrawn for the first 10 seconds, until it is completely shut off at the 10 second mark. With this fuel shutoff time, the draft controlling equipment had a chance to react. With the 1 second fuel shutoff time, the pressure reaches its maximum at the 2½ second mark, which does not leave any time for the system to react. These curves are based on 100% loading conditions at the time of the trip.

3.2 Loss History

Loss experiences indicate that boiler furnace implosions have caused severe damage to property and extensive business interruptions. The damages to equipment could increase in the near future as emission control requirements for firing of boiler furnaces dictate the addition of flue gas cleanup systems.

3.3 Illustrative Losses

3.3.1 Control Air Failure Shuts Dampers.

An arcing fault in the switchgear caused a 100% shutdown of the coal mills. Following restoration of power, damage to the boiler setting (14 buckstays) was found. Maximum inward deflection was measured at 2 in. (50 mm). Repairs reset boiler walls to a maximum deflection of ½ in. (13 mm) corner to corner. Damage was directly attributable to loss of control air upon electrical power loss. Primary, secondary, and forced air dampers closed upon loss of control air. Before ID fans could be tripped, draft gauges pegged at –10 in. water (2.49 kPa, 24.9 mbar). Under test conditions, the ID fans are capable of producing vacuum of –26 in. water (1.49 kPa, 15 mbar).

3.2.2 Phase to Ground Arcing Causes Pulverizers to Shut Down.

Phase to ground arcing occurred when returning a 440 volt system to service. Voltage drop in the electrical system caused three of six pulverizers to shut down. Furnace pressure monitors sensed –5.5 in. of water (1.37 kPa, 0.014 bar) which caused an immediate shutdown of the remaining three pulverizers, primary air and ‘‘B’’ exhaust system. With all fuel tripped, furnace pressure dropped to a –15 in. water (3.73 kPa, 37 mbar) which resulted in a collapse of a vertical section (approximately 40 ft, 12.2 m) of duct between the economizer and air heater. The walls of the duct were collapsed as much as 8 ft (2.4 m). Damage in this case could have been worse. The boiler structure was designed for a pressure of ±7 in. of water (1.74 kPa, 17 mbar). If the duct did not give way allowing for a pressure release, the boiler and setting could have been severely damaged.

3.3.3 Lack of backup power system contributes to implosion.

This unit is identified as a large utility unit rated at 5,841,000 lb stm/hr, 2600 psig (18 mPa, 179.2 bar) and 1005°F (540°C) superheat and reheat. Damage consisted of approximately 30 tubes split or ruptured. Three furnace walls were drawn in a maximum of 30 in. (760 mm). Roof tube refractory had to be replaced. Penthouse buckstays fell to the floor. Several buckstays had to be replaced. Left and right front corners were opened up. Oil gun assemblies were damaged. Skin casing on three walls along with insulation had to be replaced. This is the most severe case of boiler implosion experienced in U.S. history. The cause of the implosion was determined to be loss of primary power to the control system which kept the ID fan from tripping upon high furnace vacuum trip. Backup system wiring (battery power) had never been completed. When this unit went back into service, the furnace walls were designed to withstand a furnace pressure of –20 in. (4.98 kPa, 49 mbar). Original design called for –12 in. water (2.99 kPa, 29 mbar).

3.3.4 Damaged instrument plug-in connector leads to implosion.

This unit is a 1000 ton/day black liquor recovery unit. It has a working steam pressure of 900 psig (6.2 mPa, 62.0 bar) at the superheater outlet with a steam temperature of 850°F (454°C). An electrical panel that contains wiring for the furnace draft system is located on the second mezzanine floor level in what is considered a high wash area. The plug-in connector for this panel was bent prior to this incident. This damaged the rubber grommet seal. Several minutes after the area was water washed, a high negative draft was recorded. When the draft condition had stabilized, the unit was inspected. Several buckstays were found to be deflected inward, some up to 2 ft (0.6 m). The tubes on the south wall were bent inward at least 9 in. (230 mm). The bent plug-in connection allowed water into the cabinet which short circuited the signals causing the FD fan control damper to close and the ID fan to speed up which resulted in the implosion.

4.0 REFERENCES

4.1 FM

Data Sheet 6-2, *Pulverized Coal-Fired Boilers*.
Data Sheet 6-5, *Oil or Gas Fired Multiple Burner Boilers*.

4.2 NFPA Standards

NFPA 85, *Boiler and Combustion Systems Hazards Code*.

APPENDIX A GLOSSARY OF TERMS

Explosion: a violent outward expansion caused by a rapid increase in pressure resulting in boiler damage due to forces in excess of yield strength.

Implosion: a violent inward contraction caused by a rapid decrease in pressure resulting in boiler damage due to forces in excess of yield strength.

APPENDIX B DOCUMENT REVISION HISTORY

January 2000. This revision of the document has been reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTAL INFORMATION

C.1 Background Information

C.1.1 Introduction

It is important in this discussion to understand the definition of implosion and its relationship to an explosion. An explosion is a violent outward expansion caused by a rapid increase in pressure resulting in boiler damage due to forces in excess of yield strength. An implosion in a boiler furnace is a violent inward contraction caused by a rapid decrease in pressure resulting in damage due to forces in excess of yield strength. Each hazard should be treated with equal weight. One is not more important than the other and both are of great concern. Therefore, a great deal of care must be taken in the design of boiler furnaces to guard against both hazards.

Safeguards and interlocks are installed as a means of controlling or preventing explosions. There can be a conflict in prevention of explosions and implosions because the implosion safeguards may allow for a momentary accumulation of unburned fuel. In explosion prevention, during a Master Fuel Trip (MFT), the first step is to stop all fuel from going into the fuel firing chamber immediately. In implosion prevention, the object during an MFT is to shut off the fuel at a slower rate (matter of seconds). The reason for doing this is to prevent rapid decrease of furnace gas temperature and pressure, thereby allowing the airgas flow equipment some time to react to the MFT.

Implosions can occur on boiler-furnaces and their associated systems that are equipped as balanced draft fuel-fired units. For the implosion to occur, enough force must be produced to overcome the design yield strength of the combustion air/gas path or furnace. Implosion prevention is of particular concern on boilers where, because of size and associated equipment, there is an extensive loss potential. Implosions have occurred in boilers fired with oil, coal and black liquor. No incidents have been reported on natural-gas-fired units because few gas-fired boilers are balanced draft

C.1.2 Factors Leading to Implosions

Two conditions can lead to boiler implosions. The first is caused by a rapid decay of furnace gas temperature and pressure following a rapid reduction in fuel input or a master fuel trip. The second is the result of poor operation or malfunction of combustion air/flue gas flow regulating equipment resulting in the furnace being exposed to the full ID fan head capability. The latter is divided into two categories: abnormal fan operation and other related air/gas flow path equipment problems.

C.1.2.1 Master Fuel Trip

A master fuel trip can be initiated by either a trip or loss of the fuel supply system or a separate system interlock. It is important to understand the relationship of the furnace pressure and volume to the furnace temperature. This relationship can be expressed by the perfect gas law,

$$PV = nRT,$$

Where P = absolute furnace pressure
V = volume of furnace
n = number of moles of gas in furnace
R = fixed gas constant
T = absolute furnace temperature

When an MFT occurs, there is a rapid decrease in the furnace temperature as the combustion ceases and the furnace begins to cool. If the air/gas flow system responds too slowly, fails to react, or a blockage occurs in the flow path and the system cannot respond, then the pressure could decrease downstream of the problem area and could cause an implosion. The slow withdrawal of fuel after the MFT occurs allows for a somewhat controlled decrease of furnace temperature.

C.1.2.2 Abnormal Fan Operation

Most fans are controlled by inlet dampers or vanes. When there is a call for a larger volume of air and the FD dampers do not react quickly enough to satisfy this demand, the furnace pressure begins to decrease.

The dampers may not operate at all, or a Forced Draft (FD) fan may trip and the control system may not react to trip a corresponding Induced Draft (ID) fan. These conditions could be caused by a momentary loss of power or by system interlocks not properly set or malfunctioning.

These problems could arise during the firing or non-firing cycle of a unit, such as a purge cycle. Fan problems could enhance the problems encountered during an MFT. The worst cases of boiler implosion result from a combination of fan problems during an MFT.

C.1.2.3 Related Air/Gas Path Equipment

Figure 2 is a schematic of a typical air supply/gas removal and cleanup system for a steam generating unit. This schematic is representative of newer units. Older installations have less complicated systems. In the future, systems will become more complicated as the necessity to control emissions adds gas cleanup equipment on new designs and refurbished older units.

The arrangement in Figure 2 includes some of this equipment, namely the precipitator (No. 7) and scrubber subsystems (No. 11). The scrubber subsystem contains a booster fan (No. 11A) to help push the combustion gases through to the stack. This fan adds to the head capability of the ID fan (No. 9) and increases the potential pressure limit that the entire system could encounter during an excursion. This arrangement represents a ‘‘worst case’’ situation with respect to potential pressure limit for a large boiler-furnace. Exposure to implosions is greater in a coal-fired unit.

Many problems can arise along the flow paths of these systems. Any set of dampers downstream of the FD fans could close or malfunction, which would shut down the air flow and cause the pressure to decrease downstream of the dampers. A damper malfunction could result from the drive shaft shearing due to fatigue, corrosion or improper installation. Controllers reacting slowly or failing to act at all to signal commands could also cause damper malfunction.

An obstruction in the air/gas system could occur especially on coal-fired units. For example, if air heaters or economizers are not properly monitored and cleaned, they could plug up with fly ash and cause not only an implosion problem, but a fire hazard as well. This blockage would cause an increase in pressure on one side and a decrease in pressure on the other side and could lead to an implosion of the ductwork and a failure of the structural supports downstream of where the blockage occurred.

C.1.3 Operational Procedures

This section deals primarily with the operation of the equipment involved in the air supply/gas removal system of a boiler furnace. The interlock and alarm section includes a discussion of the entire boiler-furnace burner interlock control arrangement.

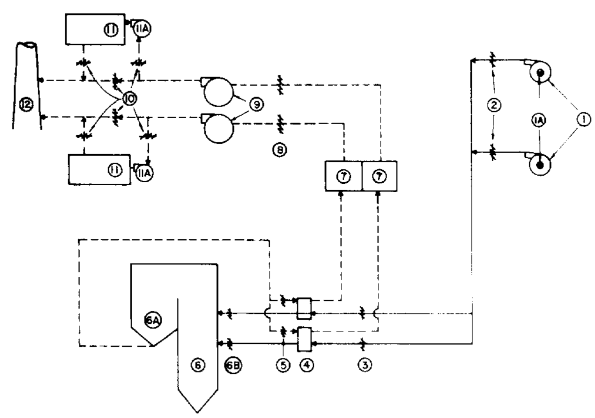


Fig. 2. Boiler air, fans, and associated equipment.

Figure 2 — Legend

Solid Line represents COMBUSTION AIR
Dotted Line represents FLUE GAS

1	Forced draft fans
1A	Forced draft fan inlet control vanes/dampers
2	Forced draft fan shutoff dampers
3	Air heater inlet dampers—Combustion Air Side
4	Air heaters
5	Air heater inlet dampers—Flue Gas Side
6	Boiler furnace
6A	Economizer section
6B	Windbox dampers
7	Precipitators
8	Induced draft fan inlet control dampers/vanes
9	Induced draft fans
10	Bypass dampers
11	Gas cleanup system (Scrubber)
11A	Gas cleanup system booster fans
12	Stack

C.1.3.1 Air/Gas System Operational Sequence

Before any fans are started, the flow path should be checked to ensure that there are no obstructions. This includes making sure all dampers, with the exception of the control dampers on individual fans which may be closed during starting sequences of their associated fan, are opened between air inlet and stack outlet.

After startup of the first fan, the associated shutoff dampers for each idle fan (refer to Figure 2) should be kept shut as necessary to prevent the flow of air from running the idle fan backwards and causing damage to the fan rotor, motor, coupling, or other associated equipment. ID fans should be started first, followed by corresponding FD fans with a check to make sure that furnace excursions are minimal. As soon as the furnace pressure conditions are stable, controls should be switched to automatic where applicable. Shutdown procedures are the opposite of startup procedures. (Detailed startup and shutdown procedures for ID and FD fans are covered in Data Sheet 6-2, *Pulverized Coal-Fired Boilers* and Data Sheet 6-5, *Oil or Gas Fired Multiple Burner Boilers*.)

Note: Manufacturer's recommendations should be followed during start-up of fans.

Note: During shutdown procedures, it is important to remember that the fan dampers should be operated in such a way as to avoid positive and negative furnace pressure excursions during coastdown of the fan.

C.1.3.2 Interlocks and Alarms

The various system interlocks are depicted in Figures 3, 4, and 5. Figure 3 shows the interlocks and alarms for the safe furnace pressure operation. Figure 4 shows the interlocks for the entire burner system in relation to the master fuel trip. Figure 5 depicts a logic flow diagram for the purge system.

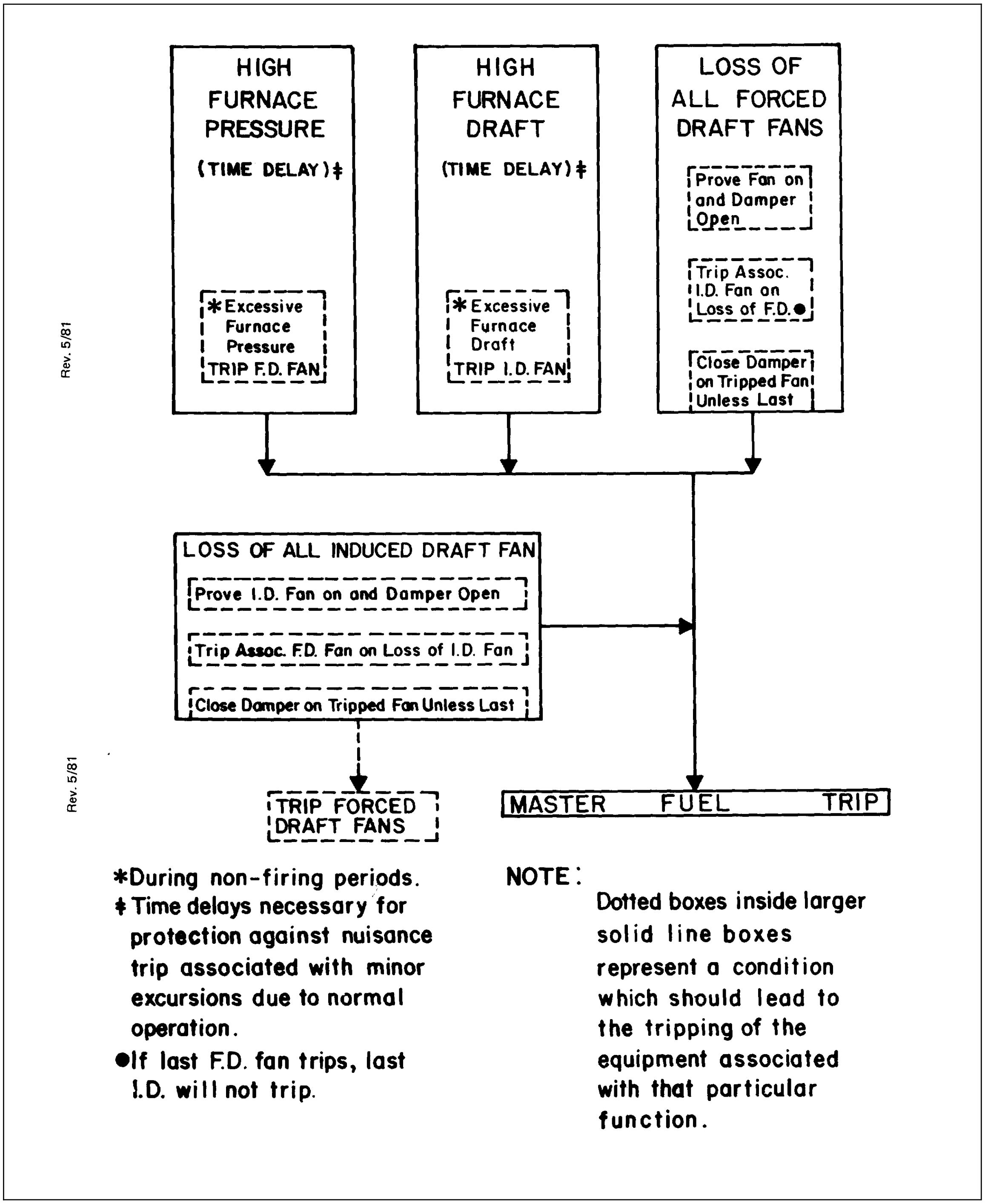


Fig. 3. Air/gas system interlocks.

High furnace pressure or high furnace draft should cause a trip of the main fuel. However, a time delay should be set into the logic, so that a momentary excursion, which does not present a hazard to the overall operation,

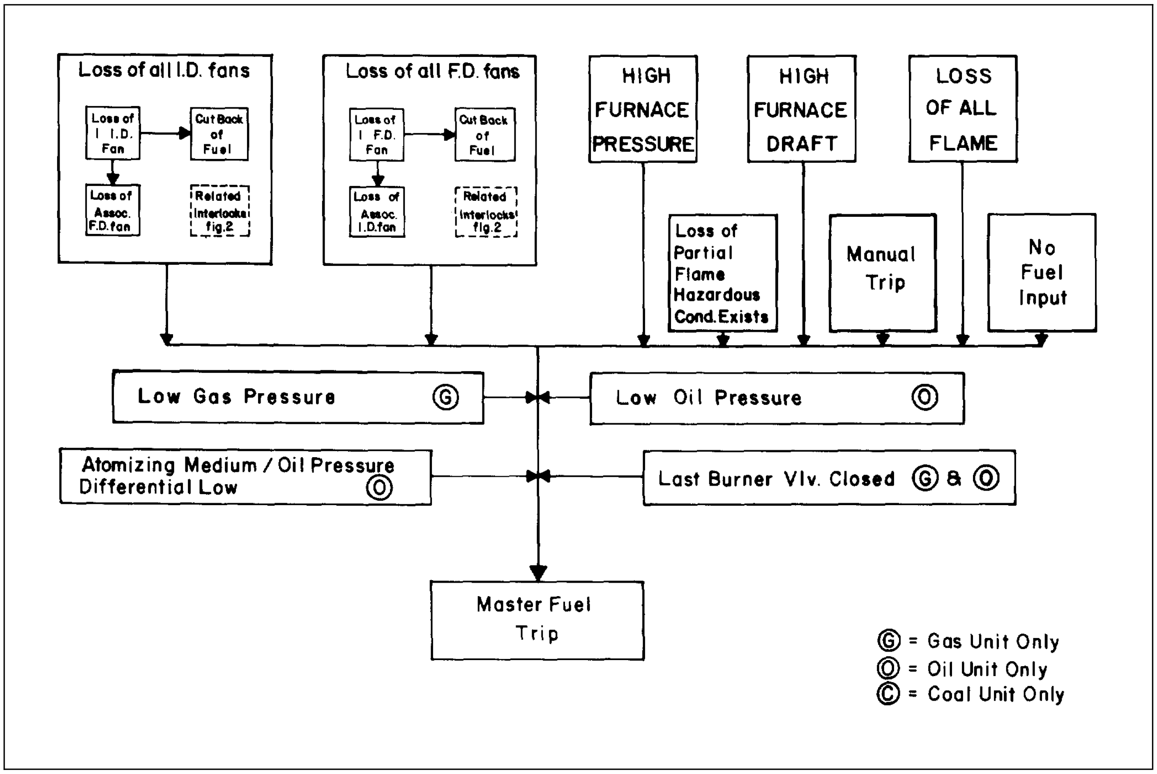


Fig. 4. Master fuel trips, system interlocks.

does not cause a "nuisance" trip. The time period mentioned above, as well as the setting for the high pressure or high draft switch, should be set according to manufacturer's recommendations.

During non-firing periods, excessive furnace pressure should trip FD fans and excessive furnace draft should trip ID fans (dotted box condition). These are subloops to the main functions which will lead to a master fuel trip.

Loss of *all forced draft fans* should trip the main fuel. During start-up interlocks should be provided to trip individual fans if they are not proved running and if dampers are not proved open. Associated ID fans are tripped when an FD fan is tripped unless they are the last pair in service. In this case, the trip of the last FD fan does not trip the last ID fan. This type of interlock sets up a loop which permits the ID fan to start first upon restart of the unit. Dampers on FD fans are shut after the fan has been tripped to avoid pressure excursions during coastdown periods unless it is the last fan. In this case, the damper should be used to control furnace pressure during coastdown.

Loss of *all induced draft fans* should trip the main fuel. During start-up interlocks should be provided to trip individual fans if they are not proved running and if dampers are not proved open. Associated FD fans are tripped on loss of ID fans. Dampers on ID fans are shut after the fan has been tripped to avoid draft excursions during coastdown periods unless it is the last fan. In this case, the damper should be used to control furnace draft during coastdown. An interlock should be provided to shut all FD fans down upon loss of all ID fans.

Some additional *alarms* that should be provided in the system are:

1. Alarm on deviation in the readings taken by the redundant furnace pressure transmitters.

2. Alarm on fan limitations caused by positive or negative furnace pressures. In other words, if the fans have been cut back in speed or other control equipment is causing a cut back in speed because of high pressure or high draft, an alarm should be sounded.

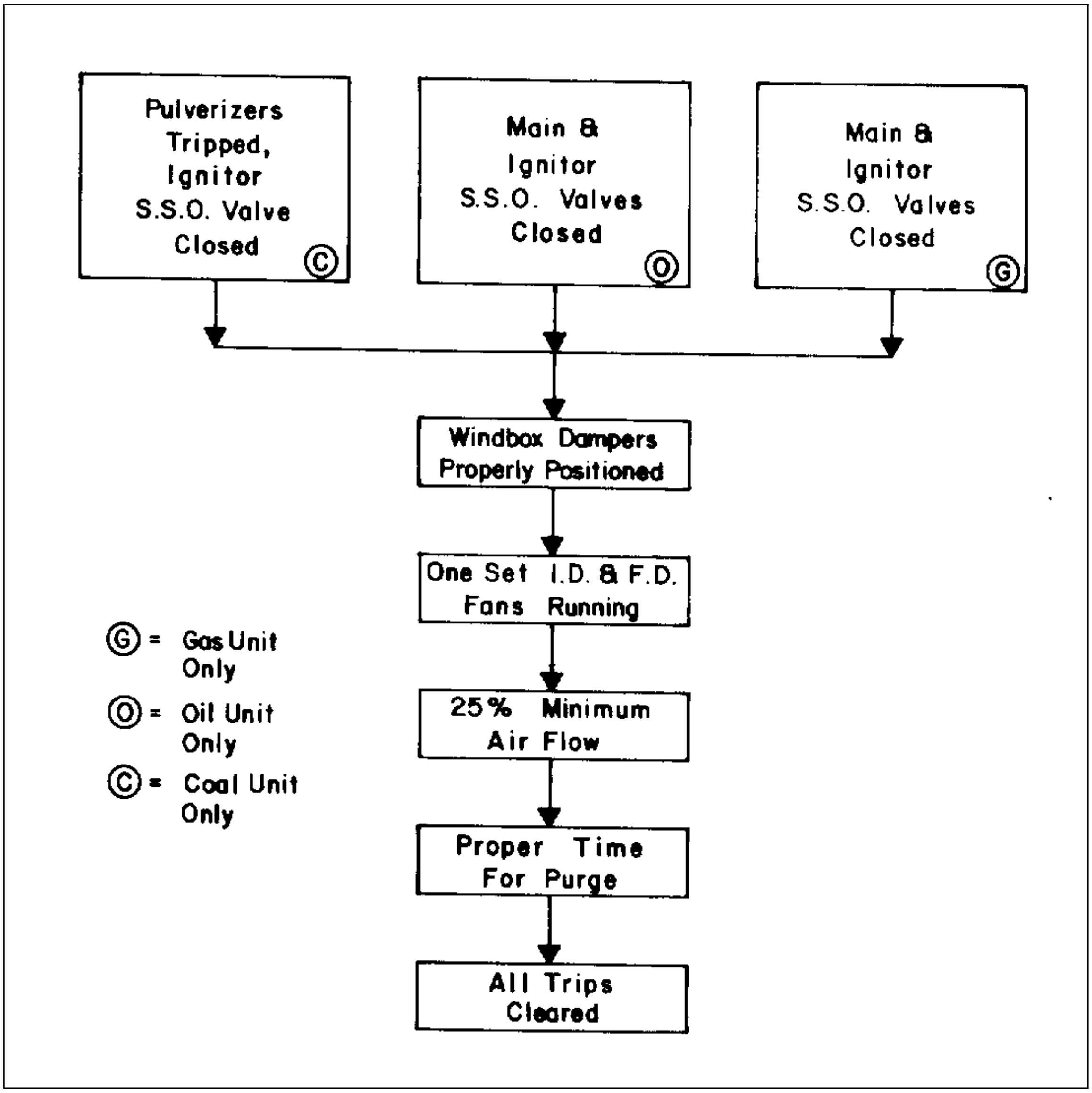


Fig. 5. Purge system logic flow diagram.

C.1.4 Discussion

C.1.4.1 Structural Design

The easiest solution to the problem of implosion prevention would probably be to design the structure, bracing and supports to withstand the greatest negative pressure that the system could produce. This pressure is the total head capability of the induced draft fans. However, this is not always the most economically feasible solution. There is a point where the cost per kilowatt to build a given unit increases dramatically as the design pressure increases. The larger the unit, the bigger the step in cost.

The types of fuel that are burned also affect the cost. The furnace volume of a coal-fired unit is perhaps 2½ to 3 times the volume of a gas-fired unit of the same size and rating. The coal-fired unit, therefore, requires more structural members for bracing and supports. The cost of a coal unit is higher than another type of unit even before higher pressure design is considered.

Designing a unit to withstand higher pressures could put the cost of the unit out of reach for most boiler-furnace users. The decision to increase the structural strength of the units will become an increasingly difficult one to make in the near future when units will require scrubbers to burn low grade types of coal.

The addition of scrubbers with booster fans could increase pressures possible during excursions to almost double what they would be without scrubbers. This is because the head capability of successive fans is additive.

In Figure 2, assume the head capability of the ID fan is 25 in. water (6.22 kPa, 62 mbar). Also assume the booster fan capacity is 20 in. water (4.97 kPa, 49 mbar). When the unit is on-line and the scrubbers are in service with the two fans (ID and booster) operating, the negative pressure possible is –45 in. water (11.197 kPa, 0.111 bar). In the case of a 100 ft (30 m) diameter unit, strengthening the unit to guard against the added 20 in. (4.97 kPa, 49 mbar) pressure from the booster fan would double the cost of the unit. Therefore, a decision as to whether or not the unit should be designed to withstand the higher pressures must be weighed carefully.

C.1.4.2 Special Controls

The conflict between recommendations for explosion prevention and implosion prevention was mentioned in the introduction. This conflict becomes evident in discussing the use of special controls. Since the problem of implosion has only within the last few years been recognized as a major problem, industry is merely on the threshold of studying the problem.

To prevent an explosion during an MFT, the main fuel must be shut off as soon as possible. Because of control logic timing, this reaction usually takes about 5-8 seconds, sometimes longer in coal units. In implosion prevention, this 5-8 seconds becomes a valuable amount of time. Maximum negative pressure occurs less than 2 seconds after loss of flame. The 5-8 seconds necessary to shut down the main fuel gives the control system a head start repositioning all draft controlling equipment. Upon loss of flame, the draft controls have time to react and the maximum negative pressure generated can be within structural design limitations. In the explosion instance, the time delay may be damaging; in the implosion instance, it is helpful. In order to have this type of fast action on dampers, the control system should be equipped with a feed forward that will control the system until the regular control system can ''catch up.''

Tests have proven that damper pneumatic control drive stroke speeds are faster than electric control drive stroke speeds. The latter take 30-60 seconds. The pneumatic drives can operate from 0.8 to 3.0 seconds. However, this does not mean that the fastest way is the best way. There are certain problems that are associated with pneumatic controls which must be considered. Some are low air supply pressure, moisture in the air, and freeze-up in actuators and air lines. The most important factor is system response time. Provided that the control system is able to respond adequately, it does not matter whether the controls are electric, pneumatic, or a combination of them.

C.1.4.3 Axial Fans

A way to limit ID fan head capability is the use of axial flow controllable pitch fans. On axial flow controllable pitch fans, control of flow is accomplished by varying the blade pitch angle. There is a maximum developed head that is produced for each blade angle. When all of these values are plotted they produce the ''stall'' line of the fan. Stall occurs when the flow to a fan is reduced. If system resistance increases for any reason, the axial fan will respond by moving to a higher operating point along the fan performance curve. If the operating point continues to move up on the performance curve, it could reach the point where it tries to produce more than it is designed for at that particular blade angle. If this happens, it will stall. This is desirable because the fan can no longer produce head until it comes out of the stall condition. (Figs. 6 and 7 show stall lines, performance curves, and the effect of variable geometry for axial fans.)

If it is a variable pitch axial fan, the blade angle will change to try to compensate for this unstable condition. The operation of the fan will move to a new performance curve with lower flow and head produced.

The stall characteristic and the variable pitch blade angles of the axial fan make it appealing for use in air/gas systems on boilers from an implosion viewpoint. However, there are other factors that should be considered before installation of axial fans. These include economic considerations as well as maintenance and reliability considerations (e.g., hydraulic assembly).

Another point that should be mentioned is that the variable geometry that is accomplished with the variable pitch blades (refer Fig. 7) can be accomplished to a certain point with the use of variable controlling inlet vanes along with either centrifugal fans or axial fans without variable pitch blades.

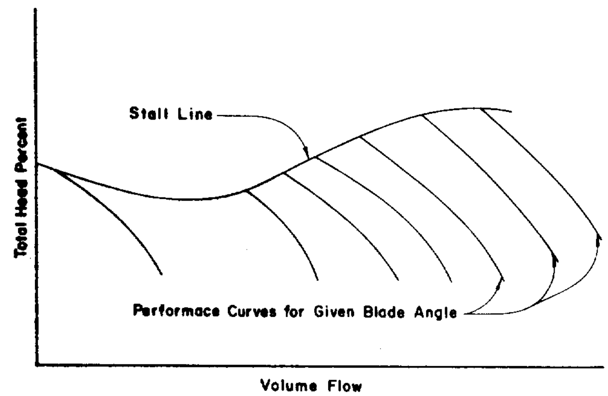


Fig. 6. Axial fan stall curve.

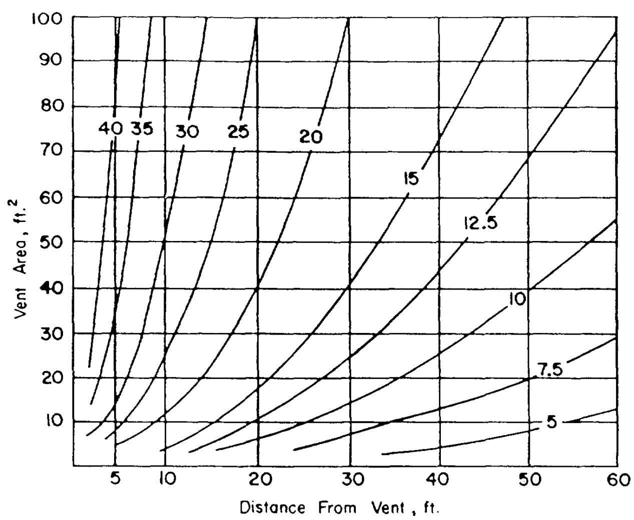


Fig. 7. Change due to unstable condition.

Note: None of these special considerations, structural design, or special controls, should be considered a cure-all by themselves. A combination of the two could be a viable solution to boiler-furnace implosion prevention.

C.2 Other Standards

Prevention of furnace implosions in multiple burner boiler-furnaces is also covered in NFPA 85, *Boiler and Combustion Systems Hazards Code*. There are no known conflicts with this standard.