Runaway Diesel Engine Impact

Controlling Runaway Diesel Engines

By Jogen Bhalla

Diesel engine runaway is a serious problem in plants and facilities where hydrocarbon emissions or leaks may occur. A runaway can be described as an engine running out of control on an external fuel source where the operator cannot shut down the engine using conventional methods. Turning off the engine ignition switch, fuel system, shutting off the solenoid or disengaging the engine's load will not stop a diesel engine. The most effective way of shutting it down is with a diesel engine air cut off valve.

Diesel engine speed is governed by the controlled amount of fuel fed to the engine through its normal fuel system and by its internal speed governor. When additional uncontrolled fuel is present in the environment in the form of combustible vapors, the engine may ingest this adding additional uncontrolled fuel intake causing the engine to over speed. Turning off the normal shut down system will only turn off the engines normal fuel source, permitting the engine to run uncontrolled by the external fuel source. In a total runaway engine situation, the result can range from minor engine damage to engine explosion, causing catastrophic damage to the equipment and surrounding facilities and/or death or injuries to personnel.

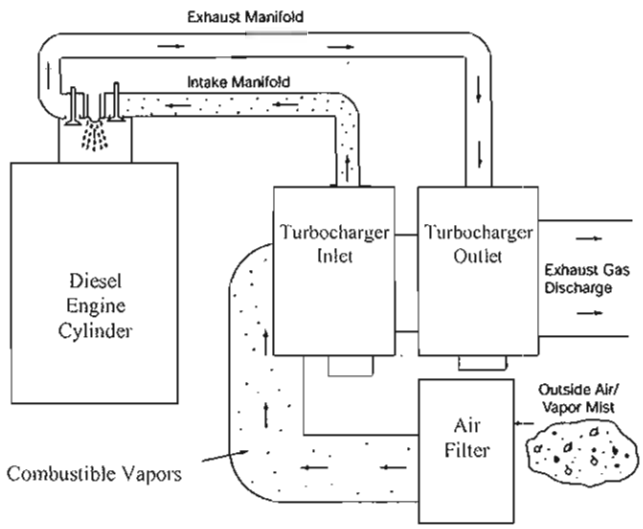


Figure 1: Typical Air Intake System-4 Cycle Diesel Engine

Engine runaway accidents have been reported by different agencies including:

U.S. Chemical Safety and Hazard Investigation Board
BP America Refinery Explosion Texas City, TX, March 23, 2005
http://www.csb.gov/completed_investigations/docs/CSBFinalReportBP.pdf,

BLSR Operating Ltd. Vapor Cloud Fire Rosharon, TX, January 13, 2003
http://www.csb.gov/completed_investigations/docs/BLSRFinalInvestigationReport.pdf,

The Marshall Democrat-News
MFA Explosion @ PetroCard bulk fuel facility (Jan 2005 Marshall, Kansas),
http://www.marshallnews.com/scripts/search/topbox.php?query=petrocard,

Tulsa World News
Oil-field blast kills one man, injures 3
August 28, 2008
http://www.tulsaworld.com/news/article.aspx?articleID=20080828_12_A11_BRISTO835078
(Article Attached)

Tulsa World News
Oilfield worker killed in blast near Chickasha, September 26, 2008
http://www.tulsaworld.com/news/article.aspx?articleID=20080926_12_ALEX158171
(Article Attached)

TheDenverChannel.com
Drilling Rig Tank Explosion Injures 3 Near Greeley
January 14, 2008
A Drilling Tank Explosion Injured 3 Near Greeley, Co. The source of ignition was a running pick up truck.
http://www.thedenverchannel.com/news/18478216/detail.html

(Continued on Page 2)

G. Nash, Chief Fire Officer, Esso Refinery, Fawley.
The Safety Aspect of Using Diesel Engines in Flammable Areas.
(Article Attached)

The Guardian
Inquest Call for New Law on Gases
(Article Attached)

According to OSHA, there have been 36 incidents related to the release of highly hazardous chemicals in the refining industry since 1992, causing 52 deaths and 250 injuries.

U.S. Minerals and Management Service, the U.S Government agency that regulates the offshore oil industry, determined that there are alarmingly high percentages of fires and explosions resulting in death and destruction. More than 20 people have been killed and 190 injured in just three accidents.

In 1985, the U.S. Department of Labor, Mine Safety and Health Administration established and enforced regulation 30 CFR 7.98, titled Technical Specifications. Per this regulation, diesel engine air intakes shall be equipped with a device to shut down the diesel engine in the event of runaway". NFPA (1999) permits installation of a manual emergency shutdown device on the intake or exhaust system to prevent engine over speed. U.S. Coast Guard requires air intake shutoff devices in certain applications. Canadian (Alberta Regulation 151/71 Oil and Gas Conservation Regulations 8.100) and European regulators (regulation EN 1834) have similar regulations since 1971 that requires that all vehicular and stationary diesel engines working in a hazardous area must have an air intake shut off valve to prevent the engine runaway condition. ISO 3046-6:1990 standard titled Reciprocating Internal Combustion Engine also requires an over speed protection device to prevent engine runaway.

Some engine manufacturers like Caterpillar, Cummins, MTU offer an emergency air intake shutoff valve as standard equipment. Research indicates, that oil and gas field service companies are not specifying air intake shut off valves thus increasing the risk of engine runaway. Air intake shut off valve manufacturers offer a complete installation kit for different engine to make it easier to install the valve in the field.

The State of California has a regulation (subchapter 14- Petroleum Safety Orders - Drilling and Production Article 35 Drilling and Well-Servicing Machinery and Equipment) that specifies that, "For a diesel engine, a quick closing valve or equivalent device that will shut off the air into the engine's air intake manifold, a means of releasing the engine compression, provided it is done in a manner that will not produce an open flame or spark or other safe means will be acceptable."

Cal-OSHA has recently approved a petition that will expand the current standard to include stationary vehicular and mobile equipment using diesel engines operating in hazardous area. Details of the new standard will be finalized in the upcoming advisory committee meeting.

Some foreign oil and gas companies from the Middle East, Africa, and Asia are requiring their stationary and vehicular diesel engines to be fitted with air intake shut off valves to prevent engine runaway condition.

By eliminating sources of ignition in mobile vehicles, refineries and petrochemical plants can improve their safety and reduce risk associated with operating equipment in hazardous environment. This safety policy should apply to all diesel engine equipped machinery including pickup trucks, fork lifts, cargo tank motor vehicles (CTMV), aerial lifts, welder's trucks etc,.

This safety policy should apply to common ignition sources in the oil and gas, chemical, petrochemical, mining and transportation industries listed below.

- Power generation (Gen Sets)
- Crane engines
- Hydraulic unit driven engines
- Portable pump engines
- Fire pump engines
- Pipeline pump drivers
- Portable welding machines
- Air compressors
- Diesel & natural gas engines
- Vapor recovery engines
- Offshore production engines
- Engines used in the drilling industry
- Fire trucks
- Hazardous materials transportation vehicles
- Ambulances
- Marine engines
- Bulk fuel transport engines
- Haulers (Tankers)
- Landfill gas boosters
- Well service vehicles
- Mining equipment engines

- Highway resurfacing units
- Aircraft mobile support equipment
- Gasoline and propane tanker trucks
- Oil gathering trucks
- Digging/trenching machinery

THE SOLUTION

Diesel engines come in a variety of design configurations and fuel schemes but handle air the same way for combustion. Therefore, providing an effective combustion air control is the key to prevent diesel engine runaway. Several manufacturers offer swing gate, guillotine and butterfly design air intake shutoff valves with local, remote control, and automatic shutdown capability. Customers prefer swing gate and butterfly design, as seen on page 4 in figures 4 and 5, due to their lightweight and compact design that makes them suitable to install in a tight engine compartment. These valves are typically made from corrosion resistant aluminum. Guillotine type valves use a spring loaded knife gate that makes them more difficult to install on compact engines, due to their overall weight and size.

Diesel engine air cut off valves are available in many sizes to accommodate different air intake piping. Installation may require special hardware that includes clamps, hump hose reducers, and special adapter elbows that are used when there are size differences between the valve and piping.

Valves are typically installed as close as possible to the engine air intake manifold. High temperature valves that can withstand 450°F are available if higher than normal engine temperatures are present. It is essential to have solid metal connections between the valve and engine. If the valve can not be mounted directly to the intake manifold (because of size and space restrictions), all rubber hoses and elbows between the valve and the intake manifold must be replaced in order to prevent the possibility of valve movement towards the engine during a shutdown.

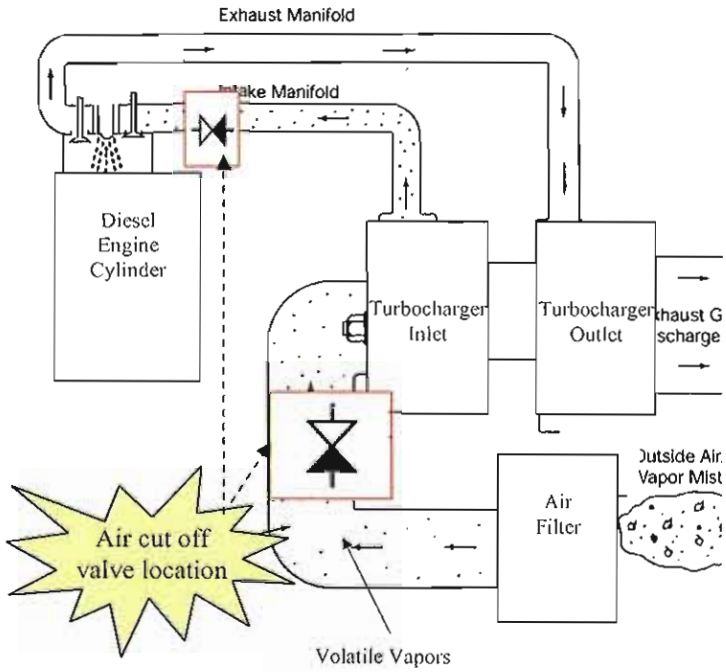


Figure 2: Diesel engine air cut off valve placement options with turbocharger

The valve actuating mechanism can be released several ways, depending on the medium available and the individual requirements. Common operation mediums can be mechanical cable, mechanical compressed air, hydraulic/electric, air/electric, electric, fail-safe or a combination of them all. To operate manually, a machine operator must push a valve control, pull a cable or flip a switch either at the operator console, a control panel or at the machine site. To operate automatically, the air intake valve is used with a speed switch that is set to trip at a specific engine over speed RPM and release the air intake valve. It is necessary to manually reset the valve in order to restart the engine.

Figure 3

"D" Valve- automatic engine shutdown in the event of engine overspeed

Pictured above are swing gate and butterfly style air intake shutdown valves

Installations on engines with dual or multiple air intakes, both naturally aspirated and turbocharged, require either one common valve or multiple air intake shut off valves that are interlocked or actuated in a manner that will cause simultaneous closure or alert of a single closure.

Summary

Any time a running diesel engine is exposed to flammable vapor, it can become an ignition source and can cause explosion. The oil and gas drilling, refining and mining activity is at an all time high level and is expected to remain high, thus increasing the possibility of more engine runaway accidents. Global manufacturers like Amot and Roda Deaco have been providing diesel engine butterfly and swing gate air intake shut-off valves for more than 25 years as a total solution complete with installation hardware and actuating mechanism. Solutions for most diesel applications are readily available, or custom solutions can be designed on a case-by-case situation. With cooperation industry wide, regulatory requirements can be mandated and with compliance enforcement, accidents would be greatly reduced and provide further protection to personnel, assets and surrounding facilities.

Chalwyn self-contained air intake shut off valve

In summary, the diesel engine runaway can be prevented with a simple low cost system that is easy and quick to install, is maintenance free and lasts as long as the engine. Everyone is entitled to work in a

safe and healthy environment and OSHA should lead in enforcement of existing regulations and add increased safety requirements for diesel engine runaway prevention.

Jogen Bhalla is a Vice President at Amot with 25+ years of global instrumentation and control, engineering, sales, marketing and business development experience in oil and gas, chemical, petrochemical, power metals and mining process automation. Contact info: 281-940-1733 Email: Jogen.bhalla@amot.com . Cell: (512)789-2751

Oil-field blast kills one man, injures 3

by: MANNY GAMALLO World Staff Writer
Thursday, August 28, 2008
8/28/2008 2:42:26 AM

BRISTOW — A Stroud man was killed and three other workers were injured Wednesday when fuel erupted from an oil well and ignited in a fiery blast, authorities said.

Creek County Sheriff's Sgt. Mike Carter said the blast occurred shortly after 10 a.m. when a lease well was being plugged.

The fire engulfed an oil derrick, spread to several trucks parked nearby and left several workers badly burned.

Carter said the name of the deceased man was being withheld until his family could be notified. The names of the injured were not available.

He said the well was being plugged by J & C Casing Pullers and Pluggers LLC of Cushing. A company spokesman had no comment.

Carter said the blast occurred about three miles northeast of Bristow and about a half-mile east of Oklahoma 66 along 201st Street.

Bristow Assistant Fire Chief Charles Conkling said that as the fuel gushed from the well, an idling truck parked nearby backfired, triggering the explosion.

Conkling said many of the workers backed off from the well after its fuel erupted and they heard the backfire, which they said sparked the blaze.

The Fire Department responded with three trucks and about 10 firefighters, "and we knocked the fire down quickly with foam," Conkling said.

Fortunately, he said, there wasn't much oil left in the well.

"All we had were some (fiery) pools of oil to deal with," he said.

None of the firefighters was injured.

"A lot of our men have an oil-field background, so we know how to tackle these fires quickly," Conkling said.

Carter, citing accounts from paramedics at the scene, said the two badly injured men, who also were from Stroud, were suffering from second- and third-degree burns.

He said one worker was on the derrick and jumped clear, injuring himself in the fall, while those on the ground were burned in the explosion.

He said they were taken — one by helicopter and one by ambulance — to Hillcrest Medical Center in Tulsa.

Carter said the third injured worker went in a private vehicle for treatment, although he didn't know where.

Carter said three trucks — an oil truck, a cement truck and an oil-field truck — were parked at the well and were heavily damaged in the fire.

He said the Sheriff's Office was awaiting the arrival late Wednesday of federal Occupational Safety and Health Administration agents to investigate the explosion.

A similar accident occurred July 23 near Mannford when crews were cleaning out a well when oil suddenly blew out and ignited on the hot exhaust manifold of a truck parked nearby.

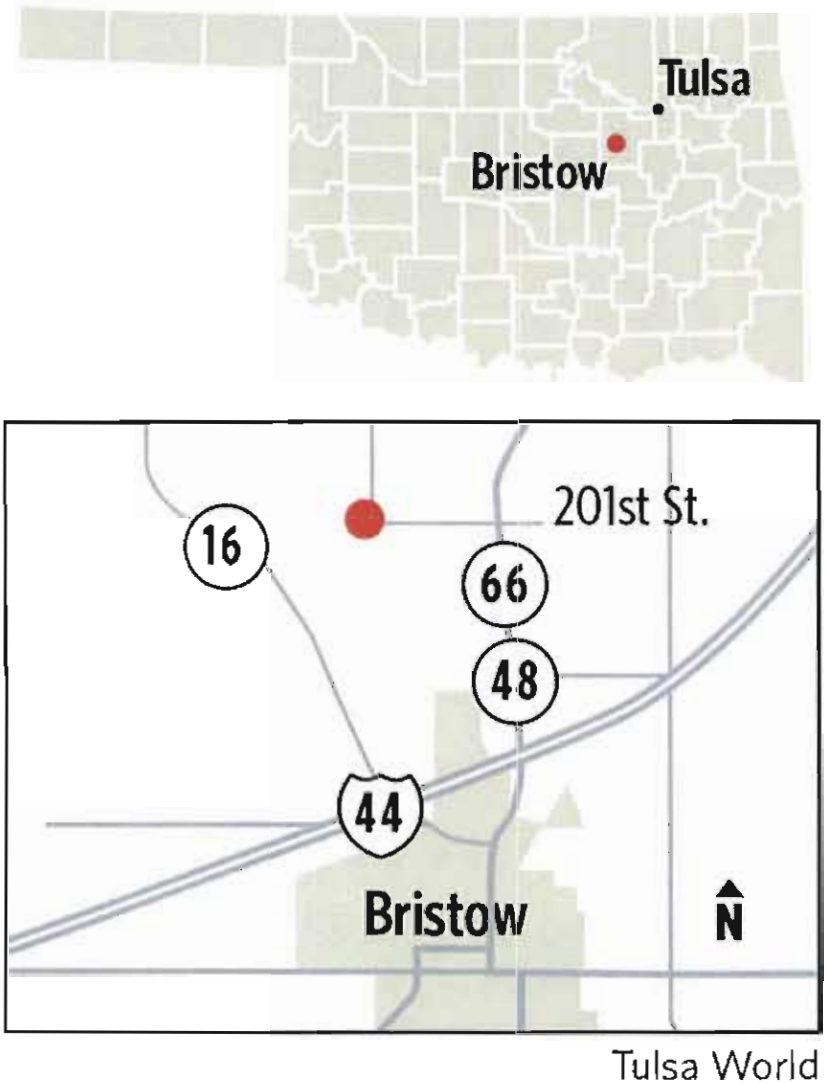
Two workers were slightly injured, one with a second-degree burn to an elbow and the other with first-degree burns on the back of his neck.

Both were treated at a Tulsa hospital and released.

Manny Gamallo 581-8386
manny.gamallo@tulsaworld.com

Associate Images:

Oil well explosion



Return to Story

Oilfield worker killed in blast near Chickasha

by: The Associated Press
Friday, September 26, 2008

ALEX — An oilfield supervisor for Weatherford L.P. has died after suffering third-degree burns in a rig explosion in Alex.

Officials say 31-year-old William Shreve suffered burns over 90 percent of his body when a truck left running apparently sparked a natural gas pocket in the field southeast of Chickasha.

Lindsay Fire Chief Jay Selzer says Shreve went to the truck to shut off the engine when it exploded.

Shreve was taken to Integris Baptist Burn Center in Oklahoma City where a spokeswoman says he died at 5:20 Friday morning.

Return to Story

THE SAFETY ASPECT OF USING DIESEL ENGINES IN FLAMMABLE AREAS

by G. Nash, Chief Fire Officer, Esso Refinery, Fawley

A number of fires have occurred in the past and subsequent investigation has shown that the possible cause of ignition was 'over-speeding' of a diesel engine. The problem was highlighted when a 'fatal' fire and explosion occurred at a large chemical plant.

The cause of the fire was found to be the diesel engine of a Simon hoist which 'ran-away' when it drew in a mixture of cyclohexane vapour and air. Diesel engines will over-speed to valve bounce or even destruction under these circumstances. In this case the engine speed increased to such an extent that valve bounce occurred, thus producing a flash back through the air cleaner.

The same hazard, of course, may present itself in any oil refinery, chemical works, oil terminal, or ship's engine room.

The Esso Company were quick to recognise the hazard and a research project was immediately instigated. A very simple device, which is relatively inexpensive to make and simple to install, and which is the subject of a provisional patent application No: 27316/70 dated 5th June 1970, has been devised and developed at the Esso Research Centre, Abingdon, in collaboration with Esso Chemical Ltd., Fawley.

It is now in use on operational equipment both mobile and stationary, at Fawley Refinery.

Studying operations involving diesel engines at Fawley it was decided that we needed to fit some device on both stationary and mobile diesel engines which operated in areas where there was a possibility of a gas or vapour release. Our approach to truck manufacturers showed that the only system they were able to offer was to fit a driver operated snap shut butterfly valve in the induction piping. After consideration we rejected this solution for the following reasons:

(a) It would not protect an unattended engine.

(b) If the driver panicked, and in the circumstances envisaged this could happen, it is probable that he would not have the presence of mind to operate the stop valve.

Further investigations of the market showed that the type of automatic device that we considered essential for our requirements was not available. Because of this, we studied the problem with a view of developing our own protective device.

Study of the variables associated with engine speed revealed that the most likely source of energy for operating an automatic device was the air induced into the engine. Working from this basis, we have developed the protective device described as follows.

The device comprises a spring loaded poppet valve fitted upstream on the air inlet manifold which can be critically adjusted such that it will permit an engine to run at its normal maximum governed speed. As soon as that speed is exceeded the valve will snap shut, against the spring pressure and will remain so until the engine stops. A further feature of this valve is that it is free to close in the opposite direction without resistance, thus providing a safeguard against the engine running backwards.

The valve is operated by the pressure differential across the valve seat. As the amount of injected air (or vapour) increases the pressure differential increases until the predetermined engine speed is reached, at this speed the pressure differential becomes greater than the force exerted by the spring and the valve slams shut. The closing action is instant and complete. We believe that this device meets our full requirements for diesel engine overspeed protection in that it has the following attributes:

(a) It's simple—thus cheap and easy to install.

(b) Is fully automatic.

(c) Should require little or no maintenance.

(d) Foolproof—the installation is such that it would be extremely difficult to interfere with.

We have successfully carried out road tests on a truck and find it will operate at all throttle conditions but still retain its overspeed control capability. We have also simulated the conditions of a vapour release by deliberately inducing butane into the induction manifold. On each occasion the engine was instantly stopped when the preset speed was reached.

In addition to being excited by ingesting flammable vapours diesel engines can be caused to run away for the following reasons:

1. Failure of the inherent engine governor, i.e. such as a broken linkage.
2. By the engine overheating or overturning when the sump oil will become the fuel.
3. When the air cleaner bath is overfilled.

The device we have developed will provide protection against all of these conditions.

With respect to our own plans at Fawley, it is our intention to protect all diesel engines operating within hazardous areas in the near future. This requirement is likely to cover long term contractors as well as Esso owned machines. The Esso Petroleum Marine Department is also considering fitting the device to its ships' engines.

For information other systems of protection were considered, briefly these were:

(a) Blanketing with inert gas. This is an effective way of stopping an engine, and has received wide acclaim. The main drawback is however that it is difficult to automate. Such a system would be costly to develop and expensive to produce, since sensing devices such as explosimeters or vibration detectors would be needed as triggering devices. The equipment would be delicate and a high degree of maintenance would be essential.

(b) A butterfly valve fitted in the induction piping operated by a trip from the inherent engine governor or by an externally mounted additional governor. After considerable research this approach was rejected, because of the wide variety of engines requiring different expensive modifications.

INQUEST CALL FOR NEW LAW ON GASES

BY OUR CORRESPONDENT

The Home Secretary's special advisory committee is to make recommendations for legislation on the conveyance of petroleum gases. This was disclosed yesterday at an inquest at Hull by Dr James Jeacock, a Home Office explosives expert, who gave evidence of the probable cause of a propane gas explosion which injured 19 people, including three children.

The jury returned verdicts of misadventure on Mr Paul Norman Brookes, aged 49, a fish dock worker, of Wasdale Avenue, Hull, and Mr Keith Winter, aged 22, a British Transport policeman, of Normanby Avenue, Beverley, who, it was said, were both "terribly burned" in a sheet of flame which swept up the port's fish dock subway road after a propane gas tank on a lorry had hit a railway bridge.

After hearing 19 witnesses the coroner, Dr Philip Science, said the explosion appeared to have started in a diesel-engined fish lorry which had been driven into the subway after the lorry carrying the gas tank had struck the bridge.

"The driver and his passenger got down, leaving the engine running, and it started to rev loudly for no apparent reason," the coroner said. "The theory is that the propane gas got into the engine through the air intake and this in turn sent out flames through the exhaust system."

Dr Jeacock, who said he had made a special report to the Home Secretary, told the jury that the top of the propane gas tank was 12ft. from the ground and the bridge was 11ft. 3in. from the road. The valve on top of the tank was damaged and the heavy gas seeped into the subway.

AIR BARRIER

The front of the fish lorry became immersed in flame which swept through the tunnel. A barrier of air prevented the flames from reaching the gas escaping from the tank because the driver had backed his lorry from under the subway.

Mr Kenneth Jones, of the forensic science laboratory, Harrogate, said he had heard of diesel-engine vehicles which could not be stopped in concentrations of gas. It was possible that the ignition source of the diesel engine caused the explosion.

Police-Constable John Richardson said the driver of the BRS articulated lorry carrying the gas tank, Mr Alexander Raymond Wier, of Warrenner Close, Dunscroft, Doncaster, told him that the tank was covered by a tarpaulin when he left Doncaster and said: "I was not told what was in the tank. I thought it was empty. There was nothing in the delivery paper to say it was propane gas."

He had not checked the height of the load and he did not remember seeing the height notice board at the entrance to the subway. Police-Constable Richardson said that, when cautioned, Wier said: "I do not know. It is my fault all those people were burned." Then he collapsed.

Wier was sworn before the coroner, who said he did not propose to take evidence from him. In his summing-up, the coroner said there was no evidence of negligence and there was no evidence that Wier was driving recklessly or that he did not care if he had an accident or not. But he could possibly have been driving without due care and attention.

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The Guardian

Recommended Practice for Occupational Safety for Oil and Gas Well Drilling and Servicing Operations

API RECOMMENDED PRACTICE 54
THIRD EDITION, AUGUST 1999
REAFFIRMED, MARCH 2007

9.13.6 Pressure relief devices shall be set to discharge at a pressure equal to or less than the rated working pressure of any pump, piping, hose, or fitting that the devices protect.

9.13.7 The inside diameter (ID) of piping on the pressure and discharge side of pressure relief devices shall at least equal the ID of the pressure relief devices. The piping shall be such as to prevent obstructions and minimize restrictions to flow.

9.13.8 Positive displacement pumps shall be equipped with pressure relief devices that discharge to the circulation system or other acceptable location.

9.13.9 Automatic air pressure controls should be provided for operations such as air cleaning, sandblasting, etc.

9.13.10 All pump houses should be equipped with two (2) exit doors that lead in different directions to the outside.

9.13.11 Shear-pin pressure relief valves shall have the valve stem and shear pin enclosed to prevent accidental contact and to prevent the shear pin from flying when sheared. The enclosure shall be so designed and attached that it cannot fly off. Only the correct shear pin shall be used when replacement is necessary.

9.14 GENERATORS, MOTORS, AND LIGHTING

9.14.1 All electrical conductors and switch gear shall be sized in accordance with NFPA 70.

9.14.2 Rig generators on land locations should be located at least 100 ft (30.5 m) from the wellhead upwind considering the prevailing wind direction to isolate a possible source of ignition. Equivalent safety or protection measures should be taken where terrain, location, or rig configuration conditions do not permit maintaining such distance.

9.14.3 All generators should have an overload safety device that will provide protection from shorting and burnout.

9.14.4 When adequate illumination cannot be made available by other means, safe portable lights should be provided. Where possible, floodlights in use should be placed in positions so as not to impair vision of persons in the work area. Operations should not be performed using vehicle headlights as a substitute for rig lighting.

9.14.5 All electrical extension cords shall be properly insulated and plugs shall be in good condition.

9.14.6 Rig lighting and fixtures shall be of appropriate electrical classification for the area in which they are located. See API RP 500 and API RP 505.

9.14.7 Light fixtures should be placed and maintained to provide illumination for work areas in conformance with ANSI/IES RP7 1988: *Industrial Lighting*.

9.14.8 The shale shaker motor and area within 5 ft (1.5 m) shall have Class 1, Division I safeguards as described in API RP 500. The shale shaker motor shall be a type approved for Class I Division I service (see API RP 500) and maintained in accordance with the requirements of this classification.

9.14.9 Repairs to electrical equipment shall not be performed unless the power source has been isolated and the control has been locked out/tagged out, and the person making the repairs is authorized to do so.

9.14.10 Rig lighting equipment in the derrick or mast, tanks, and on the rig floor, not specifically addressed in API RP 500 or API RP 505 should be enclosed and gasketed.

9.14.11 Electric motors, generators, and control panels shall be grounded.

9.15 INTERNAL COMBUSTION ENGINES

9.15.1 Emergency shut-down devices that will close off the combustion air should be installed on all diesel engines.

9.15.2 Rig power emergency shut down devices should be actuation checked no less than once weekly to determine that they are in proper working condition. All other internal combustion engine shutdown devices should be actuation-checked no less than once each thirty (30) days.

9.15.3 Spark arrestors or equivalent equipment shall be provided on all internal combustion engine exhausts located within 100 ft (30.5 m) of the wellbore.

9.16 INSPECTION OF CRITICAL EQUIPMENT

9.16.1 Critical equipment should be periodically inspected as recommended by the manufacturer or in accordance with recognized engineering practices.

9.16.2 When using nondestructive testing (NDT) methods, certified inspectors per API 510 should conduct the tests in accordance with recognized methodology and acceptance criteria. Certified NDT inspectors shall be trained per ASNT RP No. STN-TC-1A.

9.16.3 Other types of inspection should be conducted by qualified personnel.

10 Drilling and Well Servicing Rig Electrical Systems

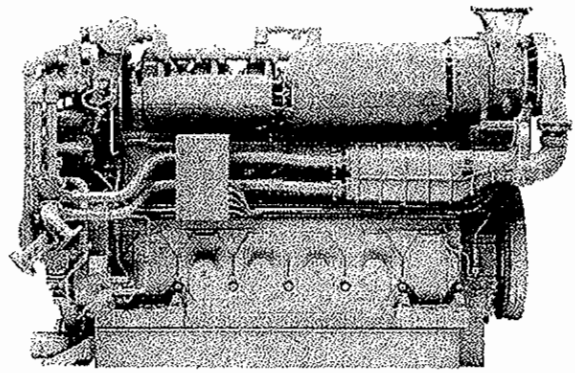
10.1 WORK IN PROXIMITY TO EXPOSED ENERGIZED POWER SOURCES

10.1.1 Neither equipment nor machines on rigs (includes guylines) should be operated closer to power lines than the recommended minimum clearances shown in Table 2, except when such lines have been deenergized and visibly grounded or when barriers are present to prevent physical contact with the lines.

CATERPILLAR®

C280-6 Petroleum Engine

2320 bhp (1730 ekW)
900 rpm



Shown with
Accessory Equipment

CATERPILLAR® ENGINE SPECIFICATIONS

In-Line 6, 4-Stroke-Cycle-Diesel

Bore	11.0 in. (280 mm)
Stroke	11.8 in. (300 mm)
Displacement	6,773 cu. in. (111 L)
Aspiration	Turbocharged-Aftercooled
Compression Ratio	13:1
Rotation (from flywheel end)	CCW or CW
Capacity for Liquids	
Cooling System	175 U.S. gal (661 L)
Lube Oil System (refill)	130 U.S. gal (490 L)
Low Idle Speed	350 rpm
Rated Speed	900 rpm
Engine Weight, net dry (approx)	34,496 lb (15 680 kg)

FEATURES

Emissions
Meets EPA Non-Road Tier 2/Marine Tier 2/EU Non-Road Stage II emission requirements and compliant with IMO standards for off-shore applications. Tier 2 refers to EPA (U.S.) standards. Stage II refers to European standards.

Single Source Supplier
Caterpillar®
- Casts engine blocks, heads, and flywheel housings
- Machines critical components
- Assembles complete engine

Ownership of these manufacturing processes enables Caterpillar to produce high quality, dependable product.

Factory-designed systems built at Caterpillar ISO 9001:2000 certified facilities.

Testing
Prototype testing on every model:
- proves computer design
- verifies system torsional stability
- functionality tests every model

Every Caterpillar engine is dynamometer tested under full load to ensure proper engine performance.

Unmatched Product Support Offered Through Worldwide Caterpillar Dealer Network
More than 1,500 dealer outlets with Caterpillar factory-trained dealer technicians service every aspect of your engine.

99.7% of parts orders filled within 24 hours worldwide.

Caterpillar parts and labor warranty

Preventive maintenance agreements available for repair before failure.

S•O•S℠ program matches your oil sample to Caterpillar set standards to determine:
- internal engine component condition
- presence of unwanted fluids
- presence of combustion by-products

Web Site
For all your petroleum power requirements, visit www.cat-oilandgas.com.

STANDARD EQUIPMENT

Air Intake and Exhaust System
Charge air cooler
Air inlet shutoff
High flow turbocharger
Dry manifold with soft or hard shielding

Basic Engine Arrangement
In-line engine with one-piece grey iron cylinder block
Individual cylinder heads with four intake/exhaust valves
Right- or left-hand service side available

Control System
Dual Caterpillar ADEM™ A3 electronic engine control modules with electronic unit injector fuel system
Rigid wiring harness (10 amp, 24 volt power required to drive electronic control modules)

Cooling System
Single or combined system
Engine mounted freshwater and seawater pumps
Engine coolant water drains

Fuel System
Engine operates on MDO
Engine-driven fuel transfer pump and an electronic unit injector for each cylinder
Engine-mounted duplex fuel filters
Electronically controlled unit injectors
Flexible connections

Lube Oil System
Top-mounted crankcase breather
Two centrifugal oil filters with single shutoff
Gear-driven pump
Duplex oil filter
Crankcase explosion relief
Oil filler and dipstick

Monitoring, Alarm, and Safety Control System
Alarms and shutdowns provided as required by marine society for unmanned machinery spaces Marine Monitoring System II or Engine Control Panel are available.
Included:
Temperature, pressure, and speed sensors
Optional:
Oil mist detector or particle detector

General
Four lifting eyes mounted to cylinder heads
Caterpillar yellow paint
Parts books and maintenance manuals
Shrink wrap

Optional Supplied Equipment
Torsional coupling
Fresh water heat exchanger
Fuel cooler
Emergency pumps and connections
Jacket water heater
Flexible connections
Anti-vibration isolators

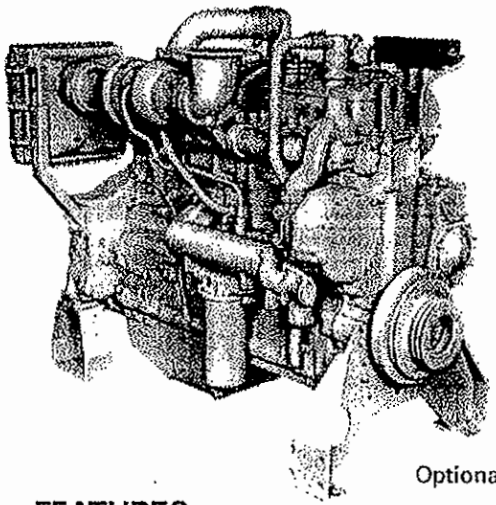
CATERPILLAR®

Petroleum Oil Well Service Engine

3406C

490 bhp/366 bkW
2100 rpm

1996 EPA and Carb Non-Road Emissions Certified



Shown with Optional Equipment

SPECIFICATIONS

In-Line, 6 Cylinder, 4-Stroke-Cycle Diesel
Bore—in (mm) 5.4 (137)
Stroke—in (mm) 6.5 (165)
Displacement—cu in (L) 893 (14.6)
Low idle — rpm 600
Rotation (from flywheel end)... Counterclockwise
Capacity for Liquids—U.S. Gal (L)
Cooling System (engine only) 8.5 (32.2)
Lube Oil System (refill) 9.0 (34.1)
Engine Weight, Net Dry (approx)—
lb (kg) 2958 (1343)

FEATURES

- **FUEL ECONOMY**
  Consistent performance, variable-timed fuel injection, broad rpm turbocharger match, excellent fuel economy over entire operating range.
- **RELIABILITY AND DIESEL DURABILITY**
  Diesel tough components, precise balance, and conservative speed for smooth operation and long engine life.
- **FLEXIBLE APPLICATION RANGE**
  High torque rise, big displacement, convenient installation, more performance for your money.
- **WORLDWIDE PRODUCT SUPPORT AND PARTS AVAILABILITY**
- **MANUAL SHUTOFF LEVER**

STANDARD EQUIPMENT

Cooling
lube oil, thermostats, housing
Crankcase breather
w/threaded pipe connection
Exhaust
water cooled
Filters, right side
fuel, lube oil
Flywheel and flywheel housing
SAE No. 1, Allison compatible
Governor control
spring loaded breakover
Mechanical tach drive – single
Oil level gauge
"positive lock" gauge on each side
Pumps
fuel priming and transfer
centrifugal gear driven jacket water, rear sump
Support
front narrow
Transmission oil cooler
Turbocharger – water cooled

OPTIONAL EQUIPMENT

Air intake
single stage, dry air cleaner
Alternators
Cooling
expansion tank, heat exchanger, radiator
Exhaust
flexible fittings, mufflers
Flywheel adapter
Instruments and gauges
fuel pressure, lube oil pressure, water temperature gauge, premium panel 8 gauge for DITA
Power takeoffs
auxiliary drives, enclosed clutches, hydraulic pumps
Protection devices
alarm switches; oil and water shutoffs, electrical and mechanical; electric overspeed shutoff
Starting
air, electric

CATERPILLAR ENGINE FACILITIES ISO 9001 CERTIFIED

STANDARD EQUIPMENT

Air Inlet System
Corrosion resistant separate circuit aftercooler core
Dual element air cleaner
Service indicator
Rear-mounted dual turbochargers

Control System
ADEM II electronic engine control

Cooling System
Torque converter connections
Gear-driven centrifugal jacket water pump
Thermostats and housings
Separate circuit aftercooler
Connections for radiator cooling

Exhaust System
Dry, stainless steel bellows exhaust manifold
Dual turbochargers with watercooled bearings
Round flange exhaust outlet, 12 in. (292 mm)

Flywheels & Flywheel Housings
SAE No. 0
Flywheel for Allison transmission (8960 or 9686)

Fuel System
Fuel filter, RH
Priming pump
Transfer pump
Primary fuel filter
Electronically controlled fuel injectors

Instrumentation
Service meter

Lube System
Crankcase breather
Oil cooler
Oil filter, RH
Oil filler, RH
Oil level gauge, RH
Rear sump oil pan
Oil pan drain valve

Mounting System
Trunion front support

Power Take-Offs
Accessory drive, lower LH
Front housing, two-sided

Protection System
ADEM II monitoring system with engine de-ration
Emergency stop logic input
Air inlet shutoff

General
Caterpillar yellow paint
Vibration damper and guard
Lifting eyes

OPTIONAL EQUIPMENT

Air compressor
Air cleaners, heavy duty
Remote air inlet adapter
Battery charger
Charging alternators
Remote speed control
Cooling system connections
Exhaust elbows, flexible fitting, mufflers
Flexible fuel lines
Remote instrument panel
Customer Communication Module
High-capacity oil pan, RH oil filter
Transmission oil cooler
Accessory drive, upper LH
Auxiliary drive shaft and pulleys
Front stub shaft
Crankshaft pulley
Air starting motor
Electric starting motor
Ether starting aid
Air pressure regulator, air start silencer
Stainless steel air, water, and oil lines
Engine barring group
Shrink wrap protection
Storage preservation
Water/fuel separator

2.5.13 Ignition Source

Although several potential ignition sources (Appendix H.16) were identified, the most likely ignition point was an idling diesel pickup truck (Figure 11). This truck was parked about 25 feet (7.6 m) from the blowdown drum, and several eyewitnesses reported seeing or hearing the truck's engine over-revving when the vapor cloud reached it.

Figure 11. Idling diesel pickup truck at north end of ISOM unit

Two eyewitnesses saw the truck catch fire, followed shortly by the vapor cloud explosion. One eyewitness saw sparks leaving the truck after a backfire and igniting the vapor cloud. While the diesel pickup has been positively identified by witnesses as an ignition point, this does not preclude the potential that the cloud was additionally ignited by other sources.

2.5.14 Blast Pressure

Once ignited, the flame rapidly spread through the flammable vapor cloud, compressing the gas ahead of it to create a blast pressure wave. Furthermore, the flame accelerated each time a combination of

U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

INVESTIGATION REPORT

VAPOR CLOUD DEFLAGRATION AND FIRE

(3 Killed, 4 Injured)

BLSR OPERATING, LTD.

ROSHARON, TEXAS

JANUARY 13, 2003

KEY ISSUES

RECOGNIZING FLAMMABILITY HAZARDS OF EXPLORATION AND PRODUCTION WASTE LIQUIDS

SAFE HANDLING OF FLAMMABLE LIQUIDS

REPORT NO. 2003-06-I-TX

SEPTEMBER 2003

Figure 15. South truck diesel engine turbocharger discharge elbow.

The T&L truck engines were not equipped with overspeed protection devices in the intake or exhaust systems. Eyewitness accounts of the over-revving are clear evidence that the air intake system was drawing in flammable vapor prior to the deflagration. Eyewitnesses reported hearing loud backfiring from one of the engines. Examination of the truck engines and debris confirmed that the metal elbow on the south truck engine (Figure 15) separated from the turbocharger housing—which is a positive indication that the engine backfired through the intake system, potentially igniting flammable vapor.

One witness also reported that the hood on the south truck lurched up just before the vapor ignited, suggesting a high-pressure impulse around the engine. The elbow and attached short piece of flexible hose (dark arrow in Figure 16) were recovered and showed no fire damage, providing further evidence that the fitting had come off and fallen to the ground before the fire ignited and destroyed the engine.[32]

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Examination of the truck engines and debris confirmed that the metal elbow on the south truck engine separated from the turbocharger housing—which is a positive indication that the engine backfired through the intake system, potentially igniting flammable vapor.

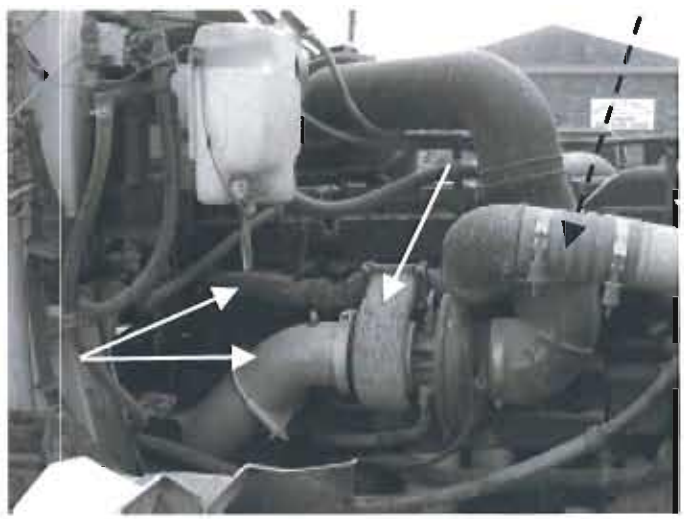

Figure 16. Diesel engine exhaust and intake system.

[32]For comparison, evidence suggests that either the north truck engine did not backfire, or the pressure wave from a backfire was not sufficient to blow the fitting off the turbocharger. A portion of the elbow was still attached to the turbocharger housing, and the remainder of the elbow and flexible hose was destroyed.