Choose the Right Electric Motors for Hazardous Locations

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Risks associated with operating an electric motor in hazardous areas range from production downtime to injury and death. Learn how to assess the operating environment and select the appropriate motor.

Electric motors can pose a serious threat when they are operated in environments that contain combustible materials. Arcs, sparks, and even high temperatures generated on the surfaces of motors can ignite hazardous substances and cause an explosion. Consequences may range in severity from minor process downtime to serious injury and even death.

Avoiding explosions is a matter of selecting the proper motor for a given hazardous environment. This requires four key pieces of information about the application: the class, division, and group classification of the environment, and the autoignition temperature (AIT) of the hazardous material in question. This article provides an overview of hazardous area designations and the motor features required for such areas. (Determining the proper area classification for a specific environment is a complicated issue and is beyond the scope of this discussion.)

Classify the operating area

In North America, hazardous classifications are defined by the National Electrical Code (NEC) *(1)* and the Canadian Electrical Code (CEC) *(2)*. The codes also stipulate requirements for the design and labeling of motors that are allowed to operate in these environments.

Class. The NEC and the CEC define three classes of hazardous locations based on the type of material present. A Class I location contains flammable gases or vapors in sufficient quantities in the atmosphere to pose a risk of explosion or ignition. Petroleum processing facilities, for example, are often considered Class I hazardous locations due to the presence of gaseous hydrocarbons.

Class II locations contain dust that is either electrically conductive or could be explosive when mixed with air. Although a substance such as flour may seem harmless, when it is distributed in air at a high enough concentration, the resulting airborne mixture can be extremely explosive. Aluminum and magnesium dusts, which are electrically conductive, will burn when in a consolidated mass, but are potentially explosive when suspended in air.

Class III locations are characterized by the presence of easily ignitable filings and flyings. Typical in industries such as textiles, these materials are too heavy to remain suspended in air and therefore tend to settle. If they accumulate around heat-producing electrical equipment such as a motor, they can ignite. Class III hazardous locations are encountered less frequently in the chemical process industries than the other two classes and generally only in a few specific sectors. For this reason, the selection of motors for Class III areas is not discussed in this article.

Division. While class is determined by the type of material present, division describes the conditions under which the material is present. A Division 1 location is one in which an explosive or ignitable material is present under normal operating conditions. The material need not be present at all times, but it will be present at least intermittently during normal operations. Division 1 locations include, for instance, environments where explosive materials are routinely exposed to the atmosphere during regular operation and scheduled maintenance. In contrast, in Division 2 locations, hazardous substances are handled or stored only under abnormal conditions, such as a containment failure that results in a leak or spill.

Group. Class I and Class II locations are further divided into groups based on the behavior of the hazardous material after it has been ignited. Groups A, B, C, and D are used for Class I environments, Groups E, F, and G for Class II areas.

Group A includes only acetylene, a colorless hydrocarbon gas that creates an intense explosion when ignited. Group D, in contrast, contains such materials as ammonia and propane. Although both acetylene and propane are hazardous, the former will react more violently when ignited. Table 1 provides some examples of the hazardous materials included in each group.

Autoignition temperature. The fourth piece of information needed to select motors for hazardous locations is the autoignition temperature (also known as the minimum ignition temperature or kindling point) of the hazardous material. The AIT refers to the minimum temperature at which there is sufficient energy for a chemical to ignite spontaneously, even without a spark, flame, or other source of ignition.

The theoretical AITs of hazardous materials are determined through standard testing procedures. In practice, however, actual AITs may vary significantly from published values because AIT is largely affected by several factors, including oxygen concentration, pressure, and system volume. Therefore, literature values of AIT should be considered guides rather than definitive parameters for the safe operation of electric motors.

The AITs of mixtures of hazardous gases cannot easily be determined. A common solution is to consider only the lowest AIT of all the component gases, although this approach is likely to be overly conservative. The AITs of various Class I and Class II hazardous materials are provided in Table 1.

Class I, Division 1 motors

Motors for use in environments deemed Class I, Division 1 must be built and labeled as explosion-proof. An explosion-proof motor has several important characteristics. First, the motor must be constructed in such a way that it will be able to completely contain an internal explosion without rupturing. It is important to note that an explosion-proof motor is not necessarily designed to prevent an explosion — only to confine an explosion within its housing. In fact, explosion-proof motors are designed under the assumption that over time, the motor's internal atmosphere will become the same as the hazardous operating environment, and an internal motor fault could then cause an explosion within the motor. Designing a motor to contain an explosion is not a simple task, as it requires careful consideration of the strength of the materials used in the enclosure and the motor hardware.

If an explosion does occur within the motor, hot gases must be able to escape after an initial buildup of pressure upon ignition. The second characteristic of explosion-proof

Table 1. Examples of different groups and classes of materials with their autoignition temperatures.

Class	Group	Hazardous Material	Autoignition Temperature °C	Autoignition Temperature °F
I	A	Acetylene	305	581
	B	Butadiene	420	788
		Ethylene Oxide	570	1,058
		Hydrogen	500	932
	C	Acetaldehyde	175	347
		Cyclopropane	498	928
		Diethyl Ether	180	356
		Ethylene	450	842
		Isoprene	398	743
	D	Acetone	465	869
		Ammonia	651	1,204
		Benzene	498	928
		Butane	287	550
		Ethane	472	882
		Ethanol	363	685
		Gasoline	246–280	475–536
		Methane	537	999
		Propane	450	842
		Styrene	490	914
II	E	Aluminum	650	1,202
		Bronze	370	698
		Chromium	580	1,076
		Magnesium	620	1,148
		Titanium	330	626
		Zinc	630	1,166
	F	Coal	610	1,130
	G	Corn	400	752
		Nylon	500	932
		Polyethylene	450	842
		Sugar	350	662
		Wheat	480	896
		Wheat Flour	380	716

Source: *(3, 4)*.

The International Electrotechnical Commission Classification Method

Both the NEC and the CEC have adopted an alternative method of hazardous location designation based on the standards of the International Electrotechnical Commission (IEC). The IEC method, which applies only to Class I locations, uses class, zone, and group to describe hazardous areas, somewhat similar to the North American method's class, division, and group designations.

The definition of Class I is the same under both systems. Whereas the NEC/CEC method categorizes the conditions under which the material is present into two divisions, the IEC method uses three zones. Zones 0 and 1 refer to continuous and intermittent hazards, respectively, and are encompassed by Division 1 (normal operation). Zone 2 is the same as Division 2 and refers to hazards that are present only under abnormal circumstances. Chart 1 below compares the definitions of Zones 0, 1, and 2 and Divisions 1 and 2.

Materials that react most violently when ignited are classified by the IEC method as Group IIC, which encompasses both Groups A and B of the North American method. Materials in Groups IIB and IIA react with less severity. Chart 2 provides a simple cross-reference of the groups for the IEC and North American methods.

Applying either of the two methods of designating hazardous locations and specifying motors suitable for use within them is acceptable. However, one method should be used throughout an entire facility. There are exceptions to this rule, and in some cases it is permissible to use equipment approved by one method in an area bearing the equivalent classification of the other system.

Chart 1. The IEC method uses zones instead of divisions to rate a hazardous location.

Presence of Hazard	NEC/CEC Method	IEC Method
Continuously	Division 1	Zone 0
Intermittently		Zone 1
Under abnormal conditions	Division 2	Zone 2

Chart 2. The IEC and the North American methods share the same definition for group, but the groupings themselves are different.

Typical Hazard	NEC/CEC Method Group	IEC Method Group
Acetylene	A	IIC
Hydrogen, Butadiene, Ethylene, etc.	B	
Carbon Monoxide, Hydrogen Sulfide, etc.	C	IIB
Gasoline, Ammonia, Ethanol, Propane, etc.	D	IIA

motors is that they are constructed in such a way that any hot gases escaping the enclosure are forced to exit through long, narrow openings known as flame paths. As gases travel along these paths, flames must be quenched and the material must be cooled to a temperature low enough to prevent a further explosion in the external hazardous atmosphere. A typical flame path can run along the shaft of an electric motor, or be designed into flanged and threaded joints in explosion-proof enclosures.

The group of the Class I, Division 1 material provides further guidance on the construction details required of an explosion-proof electric motor. In general, motors built for groups with more-severe explosion hazards require stronger enclosures and longer flame paths with tighter tolerances. Since the Group A gas, acetylene, results in the most violent explosion when ignited, explosion-proof motors for use in a Class I, Division 1, Group A location require the highest enclosure strength. Furthermore, flame paths must be longer and tighter for a Group A location than, for instance, a Group D environment containing only propane.

In addition to having an explosion-proof enclosure, motors for use in Class I, Division 1 locations must not develop surface temperatures hot enough to cause spontaneous ignition of hazardous gases in the external atmosphere. The motor is assigned a temperature code (T-code) — an identification number that describes the maximum temperature of surfaces subject to contact with hazardous materials. The indicated maximum temperature applies under all conditions, including burnout, overload, and locked rotor. Table 2 shows the T-codes and corresponding maximum temperatures for the NEC/CEC and IEC schemes.

The motor's T-code must be correlated with the AIT of the hazardous gas (or mixture) in the surrounding atmosphere. Consider, for example, a Class I, Division 1 location containing gasoline, a Group D material. The AIT of gasoline falls in the range of 246–280°C, depending on composition. Considering the lowest value in the range, a motor that is to be used in such a location must have a T-code rating of at least T2C. That is, to ensure that the gasoline will not spontaneously ignite when it contacts the enclosure, the surface temperature of the motor cannot exceed 230°C.

Devices that protect against thermal overload may be required for electric motors to achieve lower T-code rating. For instance, larger motors often have a winding thermostat — *i.e.*, a device with normally closed contacts that is connected to the motor's starter and interrupts power to the motor in the event of excessive internal temperature. In its simplest form, a bimetallic strip acts as a temperature-activated switch. When the windings of the motor reach a preset temperature, the switch opens, shutting down the motor. Using such a device allows the maximum surface temperature of the motor to remain within the limits prescribed by a particular T-code.

Table 2. The IEC method of hazardous area classification uses the same T-codes as the North American method, but omits the subclasses.			
NEC/CEC Method T-Code	IEC Method T-Code	Maximum Surface Temperature	
		°C	°F
T1	T1	450	842
T2	T2	300	572
T2A		280	536
T2B		260	500
T2C		230	446
T2D		215	419
T3		200	392
T3A	T3	180	356
T3B		165	329
T3C		160	320
T4	T4	135	275
T4A		120	248
T5	T5	100	212
T6	T6	85	185

The next step is identifying an electric motor that meets the above requirements for use in a Class I, Division 1 hazardous location. While the trained eye may be able to spot an explosion-proof motor enclosure, determining exactly what group(s) it is suitable for and the T-code rating of the motor is more difficult. Fortunately, manufacturers must supply these motors with nameplates that clearly display the class and group(s) for which the explosion-proof motor is appropriate, along with its T-code rating. This information can be included on the main motor nameplate, or presented on a separate, nearby nameplate.

An explosion-proof motor used to run a compressor is shown in Figure 1. The motor is rated for use in a Class I, Group D location and has a T-code rating of T3B, as illustrated by its nameplate in Figure 2. Note that the motor is also rated for use in a Class II environment.

Class I, Division 2 motors

It stands to reason that any motor considered suitable for a Class I, Division 1 location should also be appropriate for a similar environment containing the same hazardous materials but deemed Division 2. Indeed, an explosion-proof motor certified for use in a Class I, Division 1 location — where a hazardous material is present under normal operating conditions — may also be operated in a Class I, Division 2 area — where the hazard is present only during upset conditions — assuming the motor meets the group and T-code requirements.

However, the minimum requirements for Division 2 locations are actually less stringent than those for Division 1 locations. A totally enclosed, fan-cooled (TEFC) motor, or even an open, drip-proof (ODP) motor, may be used in a Division 2 environment, provided it does not have arc-producing brushes or switching mechanisms, which could act as ignition sources. If the motor includes a space heater, its surface temperature may not exceed 80% of the AIT of the hazardous gas or vapor.

The temperature of the motor itself must also be considered. In practice, this means that in a Class I, Division 2 location, three-phase induction motors with sufficiently low surface temperatures and no sparking parts can be used, because it is very unlikely that a spark-producing failure will occur at the same time that combustible materials are present due to a spill, leak, or other system upset.

One could reasonably conclude, then, that it would be easier to specify an explosion-proof motor for use in a Class I, Division 2 location than to convince the authority having jurisdiction over the applicable code that a non-explosion-proof motor is suitable. This approach (which has been taken by some equipment users in the past) is a safe one, but it has a significant drawback. Installation costs for labor and materials may be two to three times more for an explosion-proof motor than for an equivalent non-explosion-proof one, depending on the size of the motor.

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▲ **Figure 1.** An explosion-proof motor is used to run a compressor.

▲ **Figure 2.** This nameplate indicates that the motor in Figure 1 is rated for use in a Class I, Group D location and has a T-code rating of T3B. Note that the motor is also rated for use in a Class II environment.

Third-party certifying authorities such as Underwriters Laboratories (UL) and the Canadian Standards Association (CSA) certify motors for use in hazardous locations. Previously, hazardous-area motors were labeled with only class, group, and T-code designations. Therefore, only explosion-proof motors, required for Division 1 environments (and also suitable for Division 2 locations) were certified. Many users cited this as the main reason for specifying a certified explosion-proof motor for use in a Division 2 location. More recently, non-explosion-proof motors that meet the requirements of, and are specifically certified and labeled for, Class I, Division 2 environments became available.

Now that the certification of motors has been expanded for Class I locations, the use of explosion-proof motors in Division 2 areas should generally be avoided. Otherwise, the process for specifying a motor for such a location is very similar to that for selecting one for Division 1. The motor manufacturer must still affix a label detailing the Class (I), Division (2), and Group (A, B, C and/or D). Furthermore, the T-code of the motor, also shown on the nameplate, must identify a maximum surface temperature below the AIT of the hazardous material.

Class II motors

While Division 1 motors in Class I locations must be explosion-proof, Class II, Division 1 motors must be dust-ignition-proof. The characteristics of dust-ignition-proof motors differ from those of their Class I counterparts. One important distinction is that the enclosure of a dust-ignition-proof motor is designed to exclude hazardous materials. Whereas hazardous materials are assumed to pervade the inside of an explosion-proof motor, making an internal explosion possible, explosive mixtures of particles in air should never reach the inside of a dust-ignition-proof motor.

Since the risk of an explosion occurring inside a dust-ignition-proof motor is minimal, a major focus of its design is on maintaining a surface temperature below the AIT of the hazardous material. In practice, motors sometimes operate under a covering of dust, with constant contact between the combustible substance and the hot surface. Further aggravating the situation is the fact that an accumulation of dust can inhibit the motor's ability to dissipate heat. The T-code of a dust-ignition-proof motor is therefore just as important as the temperature rating for an explosion-proof motor — in a Class II, Division 1 location, the T-code of the motor must correspond to a maximum surface temperature below the AIT of the hazardous dust. Nameplate requirements for Class I and Class II locations are essentially the same — the class, group, and T-code of the motor must be clearly displayed.

Figure 1 shows a motor that is rated as both explosion-proof and dust-ignition-proof. The motor's nameplate indicates that the motor is approved for Class I, Group D, and Class II, Groups F and G, with a T-code rating of T3B.

As with the use of explosion-proof motors in Class I, Division 2 environments, dust-ignition-proof motors are acceptable, but not necessary, in Class II, Division 2 areas. In these locations, totally enclosed (pipe-ventilated, non-ventilated, or fan-cooled) motors may be used, provided the maximum surface temperature requirements are met.

Inverter-duty motors

In cases where an AC induction motor's load may vary, variable-frequency drive (VFD) controllers are often employed. A VFD controls the rotational speed of a motor by changing the fixed frequency of the supplied voltage to a variable frequency. The use of VFD motors improves efficiency and allows for better process control. However, VFDs can cause additional heating of the motor, which must be taken into consideration if the VFD motor is to be operated in an area classified as hazardous.

One way in which VFDs cause excessive motor heating is through harmonic currents. A VFD distorts the sinusoidal voltage and current waveform of the input, producing higher-frequency harmonics. These harmonic currents cause an increase in the overall current draw of the motor. However, they do not create any useful torque at the shaft, so only serve to increase the amount of heat generated by the motor.

A VFD can also cause additional heating by slowing the rotation of the motor shaft *(5)*. When the speed of a rotating shaft is reduced, less air flows over the motor, decreasing the air's ability to cool the motor. Therefore, a VFD-controlled motor will tend to run at a higher temperature as its speed drops.

The hazardous location approval and T-code on a motor's nameplate apply only when the motor is used in a constant-speed application.

Motors designed for use at variable speeds with VFDs are called inverter-duty motors. Inverter-duty motors can withstand signal distortions and low rotational speeds without overheating. Unfortunately, the selection of a variable-speed motor for use in a hazardous location is not simply a matter of choosing one suitable for Class I or Class II as described previously. The hazardous location approval and T-code on a motor's nameplate apply only when the motor is used in a constant-speed application. For variable-speed operation, inverter-duty motor and VFD combinations require a hazardous location approval of their own. The hazardous locations for which the motor is approved when used with a VFD must be shown separately on a nameplate (typically on an auxillary nameplate).

For example, consider a motor whose main nameplate shows that the motor is approved by the CSA for use in Class I, Division 2, Groups B, C, and D hazardous locations, and it has a T-code rating of T3A. As shown in Table 2, the motor will develop a maximum surface temperature of 180°C when used in a constant-speed application. The same motor is also approved for inverter duty. The auxiliary nameplate indicates that when the motor is controlled by a pulse-width-modulated (PWM) VFD, it is approved for Class I, Division 2, Groups B, C and D, with a T-code rating of T2A. Thus, when used as an inverter duty motor, the surface temperature will become hotter, reaching a maximum of 280°C. If this area contained the Group D material gasoline, for instance, the motor could only be operated safely without the VFD (*i.e.*, in a constant-speed application), as its 180°C surface temperature would not be sufficient to cause spontaneous ignition. However, the motor's higher surface temperature when paired with the VFD would be sufficient to cause an explosion of the gasoline. This example demonstrates an important consideration — the use of VFDs may be restricted to environments containing hazardous materials with higher AITs.

Wrap up

As discussed in this article, selecting a motor for use in a hazardous location requires more than just motor curves. Here are some quick tips to guide you in this process.

• *Classify hazardous area.* When an electric motor is to be operated in a location that contains hazardous materials, it is the responsibility of the end-user to determine the applicable class, division, and group — which is not an easy task. For help classifying areas containing Class I materials, consult Ref. 5. Guidance on hazardous area classification for dusts (Class II materials) is provided in Ref. 4.

• *Plan ahead.* Just because a hazardous location can be described in terms of class, division, and group, does not mean that a motor is readily available that meets its requirements. Group A explosion-proof motors, for example, cannot be easily obtained because applications necessitating their use are relatively rare. In such a case, you must work with the authority having jurisdiction to find a motor that is suitable.

• *Do not overdesign.* Avoid the temptation to select an explosion-proof motor for all Class I environments. Explosion-proof motors exceed the minimum requirements for Class I, Division 2 and can be significantly more expensive. The same argument applies to dust-ignition-proof motors in Class II, Division 2 locations.

• *Safety first.* Safety should be a primary concern when choosing a motor for use in a hazardous environment. It is important to understand the implications that different classifications have on the design requirements of a motor. This knowledge will allow you to provide adequate specifications to the manufacturer and ensure that you select a motor that poses minimal risk of a dangerous explosion. CEP

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