Application Guidance Notes: Technical Information from Cummins Generator Technologies

AGN 072 – Environmental Conditions

CHALLENGING OPERATING TEMPERATURES

There are technical considerations that must be initiated when using an alternator for applications where the operational conditions are accepted as being challenging, and therefore the alternator's continuous rating and associated operating temperature needs to be carefully considered.

Winding Operating Temperatures.

All low voltage alternators manufactured by Cummins Generator Technologies have an insulation system based on Class H materials for a total temperature of 180degC. These materials have been audited and approved by Underwriters Laboratories (UL).

Once in service, the life expectancy of any wound component will be dependent upon complex factors, with the operating temperature of that wound assembly being a principal factor, because as the operating temperatures increase, the following parameters are exponentially reduced;

- The dielectric strength.
- The homogenous bond strength of the wound assembly.
- A finite reduction of life expectancy (integrity) for that insulation system.

UL publish data suggests that if the wound component is operated at 180degC for some 20,000 hours, the system will incur a measurable level of 'thermal degradation', which in laboratory terms is described as a reduction to a 'half-life' condition. This does not mean that the insulation system will fail at 40,000 hours, it is simply a laboratory 'measure' of the now degraded condition of the insulation materials due to 'thermal degradation'.

For comparison, UL advises that if a Class H insulation system is operated at a Class F (155degC) rating, then the half-life increases to 120,000 hours and if operated at a Class B (120degC) rating, then the half-life increases to 640,000 hours.

It is the predicted increase of the (theoretical) half-life factor that guides engineers to nominate alternators with operational thermal rating limits based on careful consideration of the proposed in-service environment and electrical performance characteristics created / generated by the local connected load.

An experienced engineer will introduce risk assessment against all the factors that can be considered as likely to impose operational stress. This will result in a technical conclusion regarding the beneficial effect of ensuring the alternator's in-service temperatures are restricted to a 'safe' operational level.

At this juncture it must be pointed out that many factors affect the life expectancy of a wound assembly, and whilst the operating temperature may well be the principal, the engineer must never discount the following three scenarios:

1. Air borne contamination, which if allowed to come into contact with the surface of the windings thereby promoting surface tracking, or initiating chemical erosion.

2. Transiently Imposed vibration during transportation, or continuous vibration from the prime-mover, which subsequently promote relative movement between phase to phase or phase to earth insulation barriers.

3. Voltage spikes or current surges generated by the connected load that challenge the dielectric strength of the insulation system, which under extremely unstable conditions (deviations from rated voltage and current conditions) the stresses may initiate a rupture of the insulation barrier.

The following table and notes are offered as a reference guide for the operating temperature limits of a typical low voltage industrial alternator. The above recommendations should be considered against the following tabled values, which are the Cummins Generator Technologies recommended typical operating thermal limits, as measured by stator winding embedded RTD's.

Class F	Alarm	145^{o}C
Class F	Trip	165^{o}C

Class H	Alarm	170^{o}C
Class H	Trip	190^{o}C

The above values indicate the advised thermal limits for a typical industrial application where the alternator is operating at fixed voltage level, totally under the control of its own AVR and is supplying a connected load that does not exceed the rated nameplate values. The nameplate values being, voltage, current, power factor; and is a balanced three phase load with non-distorting linear load characteristics. Also, the on-site conditions do not allow the temperature at the air inlet to the alternator to exceed 40degC.

If the air inlet temperature is anything other than 40degC, refer to AGN012 Environmental Rating Factors.

Similarly for comparison on medium voltage (MV) and high voltage (HV) alternators with a Class F insulation system, the total temperature is 155degC. When operated at the Class F (155degC) rating, the half-life is 20,000 hours. If operated at a Class B (120degC) rating, then the half-life increases to 120,000 hours.

COLD WEATHER WORKING

There are some applications when a Generating Set is considered for operation at a site location where the local ambient temperature has been specified as being as low as - 40ºC, (-40ºF).

Standard commercial RIC diesel engines will not (readily) start at temperatures below - 15ºC for the following fundamental reasons, although these issues can be addressed:

- The diesel engine compression ignition process has difficulty in generating sufficient heat to 'ignite' the fuel.

- The lubricating Oil becomes extremely thick and consequently reduces the cranking speeds, adding to above situation 1.

- The diesel fuel viscosity will increase, thereby creating problems for the injection system, further adding to above situation 1.

Alternator Windings.

Extreme climates can create a situation whereby any auxiliary heat source promotes humidity changes, thereby the potential for creating a hoar frost (wet ice) on all cold surfaces including the alternator's windings. This real and serious risk of surface moisture is likely to cause a breakdown of the winding's insulation system. If the Generating Set was to be started with wet ice on the alternator's winding, then the resulting low Insulation Resistance could result in the stator winding burning out within minutes of the start-up.

This described indirect heating method should only be used under a controlled procedure of slowly, yet thoroughly, increasing the Generating Set chamber temperature such that all components are heated for a long enough period of time to ensure the alternator's windings are left free of ice and water before the Generating Set is started. If the Generating Set must be started and put into service before it can be guaranteed that all hoar frost and water has been removed from the windings, then the following function sequence should be designed into the control system. The objective is to dry the windings before allowing a voltage to be generated in the stator winding.

The AVR output must be inhibited prior to engine crank and start. This can be achieved by disconnecting the K1-K2 link on an MX type AVR or disconnecting Lead 8 on an AS/SX type AVR or switching off the excitation on a digital AVR.

With the engine now running at rated no-load speed the alternator will be un-excited and therefore, the main stator will not have rated voltage between the winding phases or to earth. The alternator's fan will move air through the alternator and this will dry off the windings.

The Generating Set should be run in this un-excited condition for a period of some ten minutes. It may be necessary to include a modification to the Generating Set control system to overcome the lack of alternator output voltage, which otherwise may cause control systems to deduce a failed generator and then a controlled shutdown of the engine.

After the 'drying' period is completed it would be prudent to check that the windings are indeed now dry before reconnecting the AVR and allowing normal excitation to occur.

Alternator Bearings.

A Generating Set may well be required to be stored or transported in very low temperatures and therefore, this does introduce a risk that the bearing loads may promote a situation whereby the bearing grease could breakdown into its constituent parts. If this Generating Set package is then subjected to vibration, then there is a real risk of bearing failure. This will weaken the hydrodynamic lubrication film and corrode the bearing's rolling elements, resulting in metal to metal contact and the likelihood of permanent damage [brinelling]. Moisture in the atmosphere will also break down the grease hydrodynamic lubrication film and eventually lead to complete breakdown of the bearing components.

The S4, S5, S6 (HC), S7 (P7), MV7, S8 and S9 (P80) range of alternators are fitted with bearings that use the high specification Kluber grease and this is designed to operate at temperatures as low as - 40ºC. However; this does rely on the bearing being regularly rotated to achieve renewed self-lubrication of the bearing surfaces. If an alternator is at rest and subjected to prolonged steady vibration, then the bearing is at risk **if** the shaft is not routinely rotated.

The S0/S1, P0/P1 and UC range of alternators have a bearing assembled with grease and seals which are 'strictly' only suitable for operating at no lower than - 20ºC. Taking a practical approach, whereby the engine and alternator assembly needs to be warmed before it can be started; it figures there is little likelihood that the bearing will actually operate at temperatures down to - 15ºC.

If the equipment package is specified to operate at a temperature below - 30ºC, then storage considerations must also be taken into account. In the case of alternators up to a rating of 250kVA, there is a need to consider the inclusion of special bearing(s) where the sealed for life bearing must be specified to have special grease and seals. Even so, stored alternators must still have their shafts routinely rotated.

The AvK range of alternators have a bearing options that are 'strictly' only suitable for operating at no lower than - 15ºC. Only by using special materials in the specific design of the individual alternator, can AvK achieve operating temperatures down to - 20ºC.

Considering Other Components.

All electronic components, including the AVR and Rotating Rectifier Unit, are all specified as suitable to operate at - 40ºC. However, all the points raised above, regarding rate of temperature change, humidity levels and hoar frost, could cause a surface moisture problem for these components.

Cooling Air Requirements.

Care should be taken to engineer a cooling air inlet scheme that does not allow the extremely cold outdoors-ambient temperatures to be directed towards the alternator's air inlet.

Extremely cold air will promote unnecessary stress to the alternator winding insulation system. The cooling air should enter the Generating Set chamber via a torturous path to ensure any air borne particles (snow, sleet, rain) will fall from the air stream before entering the chamber and furthermore, the alternator's air inlet should be protected from direct alignment with the cooling air by airflow management within the chamber.

It is expected that the Generating Set chamber will be positioned such that the prevailing weather conditions will not allow snow/sleet/rain to be driven into the chamber. This may well require explicit installation instructions for the Generating Set package and may require the provision of a protective wall, or even the chamber (container) to be fitted with motorised louvers.

Components.

At low temperatures structural material properties change. The selection of shaft steel, aluminium and plastic fans and frame/bracket/sheet metal, cables and connections should all be carefully considered to ensure their ability to cope with operational conditions will be maintained under specified site conditions. Low-temperature Iron should especially be considered for single-bearing alternators. The risk of component failure will be introduced if any component is abused and here the obvious risk is with the barring of rotors, which is not allowed as it will initiate stress, and at low temperatures the fan blade will be brittle and it may eventually break.

All the above described aspects are equally applicable to component assemblies incorporated within the Generating Set equipment package and therefore, must be duly considered by the Generating Set designer.

The following list is aimed as a checklist-prompt for that design team:

Electric Motors	Electrical wiring
Cooling Fans	Internal lights
Fluid Pumps	Door seals
Drive Belts	Door catches
AVM's	Hose Locks

For guidance on the storage of alternators, refer to AGN031 Alternator Storage.

HUMIDITY

It is very important to clarify matters relating to humidity and its practical effects on an alternator in certain applications.

First of all, a general definition of humidity is the 'amount of water vapour contained in the air'. This can be qualified and quantified in a number of different ways. Let us seek clarity on the different terminologies of humidity that are in use today.

- Absolute Humidity (AH) (volume basis) - This is the quantity of water in a particular volume of air. The most common units of measure are grams per cubic meter (g/m^3).

- Absolute Humidity (AH) (mass basis) - Also known as 'Mixing' or 'Humidity' ratio, or 'Moisture Content'. This is expressed as the ratio of water vapour mass per kg of dry air.

- Specific Humidity (SH) - This is the ratio of water vapour to air (including water vapour and dry air) in a particular mass. This is expressed as a ratio of kgs of water vapour per kg of total moist air.

- Relative Humidity (RH) - This is defined as the ratio of the partial pressure of water vapour (in a gaseous mixture of air and water vapour) to the saturated vapour pressure of water at a given temperature. RH is always expressed in terms of percentage (%). It is this term of Humidity that is always used by manufacturers of rotating electrical machines and Generating Sets (Reference: ISO 8528-1, page 10, para. 10).

Associated with Relative Humidity is the term 'Dew Point' (or 'Frost Point', when the Dew Point is below freezing). This is described as the point at which water vapour saturates from an air mass into liquid, or solid, form. Examples of this are rain, snow, frost, dew and condensation. Dew Point usually occurs when a mass of air has an RH of 100%.

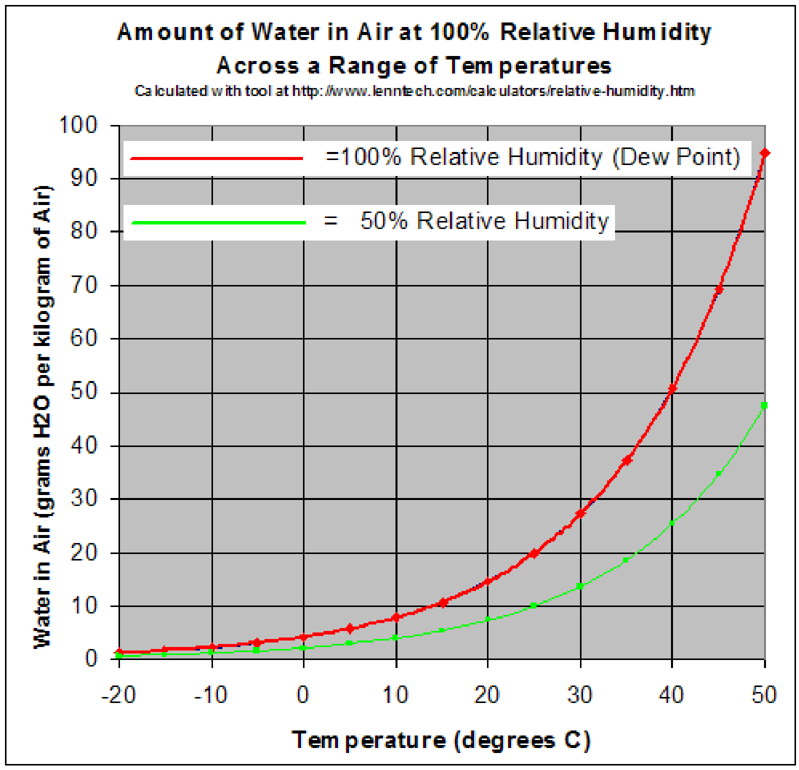
So, how do we, as alternator manufacturers, discuss RH in relation to our products?

An alternator's Owner's Manual states a Humidity level of <60% RH as the normal operating conditions that the alternator is designed for. This DOES NOT MEAN that the alternator will not operate in higher levels of RH. Merely that above this level, special measures of protection for the windings, including (but by no means the only measure) Anti-condensation Heaters, must be considered by the Generating Set manufacturer.

Now, whereabouts in the world should we be particularly interested in, with regard to the effects of RH as an important factor when we try to ensure longevity of our products whilst in service?

As stated in the above definition, RH is very much influenced by the ambient temperature surrounding and therefore, entering, the alternator and the rate of change of this temperature.

Over a range of temperatures the Dew Point will alter quite significantly, as can be seen in the following chart:



Air pressure also has an influence on RH values, although this is perhaps of more concern to the diesel engine, when considering its combustion and cooling air requirements.

Let us now consider a typical practical application where a Generating Set is located in a desert environment, for example.

In this dry and arid location, the ambient temperature will alter very significantly between night time and day time. Anything from freezing (0ºC) at night up to 50ºC during the day is possible and this ramp up in temperature could occur relatively quickly once the sun has risen. Now imagine the Generating Set being started an hour or so after sun rise. It is quite feasible that the Dew Point and therefore, 100% RH, will be low and as a consequence, condensation will probably have built up on the windings, if no special measures have been taken. A burnt out winding is a very likely end-result.

OPERATING AT HIGH ALTITUDE

This section should be read in conjunction with the guidance on altitude in AGN012 Environmental Rating Factors.

The requirements for operating high voltage alternators at high altitudes between 1000 meters above sea level (masl) and 4000 masl need particular and careful consideration.

When Generating Sets are running at high altitude locations, one of the first considerations is potential power loss due to altitude. This is a real consideration and a true phenomenon due to the lower density atmosphere, resulting in less engine horsepower capability and so less mechanical kilowatt output. The alternator's cooling capability is also reduced due to the reduced air density. In most cases the reduction due to engine power is greater than that of the alternator, however the alternator rating should always be decreased accordingly. Refer to AGN012 Environmental Rating Factors.

Extreme Thermal Effects.

The reduced air density also affects the dielectric strength of the air and consequently, this can affect the insulation characteristics within a high voltage alternator. Specifically, the potential for Corona Discharge increases as altitude increases. High altitude applications may require a special alternator with special insulation system characteristics (normally thicker main wall insulation). High altitude effects may also require special Sensing Transformers for the same reason.

Note: Within the alternator industry, generally, medium voltage (MV) refers to nominal voltages between 1000Vac and 4400Vac. High voltage (HV) refers to nominal voltages between 4400Vac and 13800Vac.

It is important to realise, the altitude de-rates detailed in AGN012 apply only to the alternator's rating at the specified temperature rise, not the complete Generating Set's rating. If the de-rated alternator kW capability remains equal to or greater than the Generating Set's de-rated kW capability, then there is no concern about operating at the Generating Set's capacity. If it is less, then the alternator will operate at a higher temperature rise and thus may require a change to a larger alternator.

Corona Effects.

The reduced atmospheric pressure at high altitude has the effect of increasing the potential for Visible Corona, in essence reducing air insulation characteristics. This phenomenon is described by Paschen's Law. It is not important to understand all the details of Paschen's Law, but rather to realise that within the range of altitudes applicable for alternators, there is a change in Visible Corona field characteristics. As altitude increases and so air density decreases, the potential for Visible Corona (purple glow) increases. Several factors influence the performance of insulation systems when operating at high altitudes. Invariably, however, they result in reduced insulation life and include:

- Environment conditions – humidity, ambient temperature, air cleanliness, etc
- Application
- Temperature rise
- Manufacturing variance - inadequate space between phase coils, poor impregnation, loose fibres and/or poorly cut tape ends, poor insertion of the coils in the stator slots, etc.

The Partial Discharge problem occurs in air-cooled machines rated at 6kV or higher.

Since discharges usually occur in air, ozone is created. Apart from its ability to destroy tissues, ozone, in the presence of nitrogen from the atmosphere, and water, creates nitric acid - HNO_3, causing further erosion of insulation. Refer to AGN012 Environmental Rating Factors, for details of the restrictions for the use of HV alternators at high altitude.

HAZARDOUS ATMOSPHERES

A potentially explosive atmosphere is one that could become explosive under certain conditions; here the danger is a potential one. An explosive atmosphere is one where a mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour or mist, exists in such proportions that it can be exploded by excessive temperatures, arcs or sparks, here the danger is a real one.

Zones.

The degree of danger varies from extreme to rare. Hazardous areas are classified into three zones:

- Zone 0 - In which an explosive gas-air mixture is continually present, or present for long periods. (Obviously an area where rotating electrical machines may not be used).
- Zone 1 - A gas-air mixture is likely to occur in normal operation.
- Zone 2 - An explosive gas-air mixture is not likely to occur in normal operation, if it occurs it will exist only for a short time.

	NEC500	NEC505	EN 60079-10	ATEX
DEFINITION	CLASS I			
Explosive gas-air mixture is continually present, or present for long periods.	Division 1	Zone 0	Zone 0	Category 1
Explosive gas-air mixture is likely to occur in normal operation.	Division 1	Zone 1	Zone 1	Category 2
Explosive gas-air mixture is not likely to occur in normal operation, if it occurs it will exist only for a short time.	Division 2	Zone 2	Zone 2	Category 3

An area that is not classified by a Zone number is deemed to be non-hazardous or a safe area.

Different definitions of hazardous areas are used by different 'Standards' bodies around the world.

Temperature Considerations.

The minimum temperature at which a gas, vapour or mist ignites spontaneously at atmospheric pressure is known as the Ignition Temperature. To avoid the risk of explosion, the temperature of any part, or surface of the Generating Set must always remain below the Ignition Temperature of the expected site explosive gas-air mixture.

When considering temperatures of a Gas / Vapour / Liquid, the difference between Flashpoint and Ignition Temperature must be appreciated. Ignition Temperature is the temperature at which the Gas / Vapour / Liquid will ignite without the presence of a spark or flame. Flashpoint is the minimum temperature at which ignition will occur with a spark or flame.

To identify the Ignition Temperature – and Flashpoint – of the Gas / Vapour / Liquid likely to be present under site conditions will require reference to Manufactures published data, or standard reference books.

Suitable Equipment for a Hazardous Zone – Generating Set.

Trying to identify the requirements of a complete Generating Set to operate in a Hazardous Area by considering the above criteria suggests that even for a Zone 2 application, a standard industrial design of Generating Set would need some very careful re-engineering.

Trying to identify the expectations of the rotating electrical machine – alternator – would suggest following the published guidance for electric motors and so considering the alternator as a 'Non-Sparking Type N machine. But an electric motor sold for this Type N application would have been approved by a certifying authority - in the same way that the marine classifying society approves a marine alternator.

Suitable Equipment for a Hazardous Zone – Alternator.

Considering just the alternator and then referring to the appropriate Standards that identify the needs for Rotating Electrical Machines in order for suitability to operate in Hazardous Zones, identifies a need for a machine of special construction.

Areas for attention include the specified requirements for minimum clearances distances between fixed and moving parts, and careful consideration of the tracking distances between various live parts to each other, and live parts to 'earth'.

Even when the alternator has been deemed to comply with the above, the consideration of maximum allowable component surface temperatures must be considered to ensure the expected site mixtures Ignition Temperature is never present.

The MAXIMUM ALLOWABLE component temperatures have an identification table, and the Specifier for the equipment should nominate a T Class:

Temperature Class	Maximum Surface Temperature in Deg.C
T1	450
T2	300
T3	200
T4	135
T5	100
T6	85

General guidance: A typical Zone 2 requirement is for T3.

Cummins Generator Technologies would never claim it manufactures IC01 open-ventilated alternators suitable for Hazardous Atmospheres.

However, these Cummins Generator Technologies products could be good basic alternators to be considered suitable for modification by others for inclusion in a complete Generating Set specially designed and rated for a Zone 2 (IEC 60079 definition) application.

Reference Standards for Hazardous Atmospheres.

IEC 60079-0:2011. Explosive Atmospheres.

IEC 60079-15:2005. Explosive Atmospheres Part 15. Equipment Protection by Type of Protection 'N'.

Equipment for explosive atmospheres (ATEX)

> Directive 2014/34/EU - The harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast). Applicable from 20 April 2016.
>
> Directive 94/9/EU - The approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres. Applicable from September 2016.

GENERATING SET DESIGN CONSIDERATIONS

STAMFORD and AvK alternators are designed to maintain serviceability in severe environmental conditions, including extreme temperature, high altitude, marine, off-shore, coastal applications in Relative Humidity up to 95%. Typical arduous applications may be Oil and Gas, Mining, Rail, RTG Cranes, on-board ships and vehicle mounted mobile units.

The installation and application of the Generating Set is to be such that contamination by airborne dust, dirt, debris, water or other contaminants is prevented from reaching the alternator cooling air inlets. This may be accomplished by fitting alternator air filters and/or louvres. If optional alternator air filters and/or louvres are fitted, there is a minimum 5% thermal de-rate for each option in addition any other relevant de-rate, on the alternator's output rating.

There is however; only so much protection that can be built in to an alternator's design and it is expected that the alternator will be incorporated within a Generating Set designed for the final application, therefore offering good environmental protection. The Generating Set design must also ensure that the operating rating, duty cycle, cooling requirements and vibration levels remain within IEC and ISO limits.

Protection in Severe Environments.

The alternator should be installed within a well-designed compartment of the Generating Set enclosure, which should fully enclose the alternator, engine and associated components. The enclosure must provide the Generating Set with weather protection on all sides, plus the top and bottom. Enclosure cooling air inlet openings must be designed to stop water droplets and airborne contaminants from entering. The large volume of air, at relatively high speed, required for the engine cooling system will normally pass through the enclosure housing area. This introduces a risk of high levels of airborne contamination entering the Generating Set housing and that some contamination will settle on the Generating Set's internal components. Careful airflow management within the enclosure is paramount, to allow sufficient airflow through the Generating Set housing for the extraction of alternator and engine radiated heat. It is important that the cooling air entering the alternator's air inlet is plentiful, cool and dry. This relies on a well-designed enclosure air inlet, which must prevent water ingress and other airborne particles, and this may require the incorporation of coalescent filters (water vane separator and dust extraction). Sometimes the engine cooling air needs to be independently derived from louvres and ducting towards the engine end of the enclosure or even ducted from the non-drive end over the top of the generator compartment. Natural drainage must be designed into the enclosure base to deal with any water or condensation that collects inside the enclosure openings or on the enclosure floor.

Anti-condensation heaters must be fitted to alternators, which are used in conjunction with the measures above. These measures must be used with some form of humidity control by way of blowing and drying the air in the enclosure with a space heating system. This system can be powered by either the local mains supply or an adjacent running duty Generating Set.

Protection against Salt Water.

With any saline environment, the possibility of sodium chloride deposits on windings, untreated metal (not necessarily just ferrous) surfaces, etc., will lead to two connected issues: – Corrosion and hygroscopic attraction of moisture leading to the insulation becoming compromised. It is important to remove as much moisture from the atmosphere in the generator enclosure as possible, both at the time of potential moisture ingress and also subsequently, when condensation may occur. Louvers should be designed with rain–trap louvers that provide a tortuous path with an intake velocity as low as possible, allowing moisture droplets to coalesce in the intake. This will leave a residual amount of moisture and most of this should be prevented from direct contact with the rear of the alternator by means of a baffle. The alternator should be allowed to draw its air from air that is passing by the machine, in the correct direction to avoid recirculation, not air that is directed at the machine. In this way, additional tortuous paths are created giving additional opportunities for coalescence and precipitation of moisture prior to entering the alternator. Creation of additional tortuous paths may give rise to additional restriction on air flow and air flow modelling prior to construction is recommended.

The enclosure should contain space heaters, sized to give at least a 5 degree Celsius temperature rise above ambient and controlled by temperature and dew point (humidity) controls. Consider air conditioning the engine enclosure for when the weather is warm and moist as this can effectively reduce the humidity without unduly heating the environment within the enclosure. Again, controlling the air conditioning using a mix of temperature and dew point controls will economise electrical loading. Anti–condensation heaters within the alternators are mandatory in this application, must be wired to a suitably sized electrical supply, and must be active when the conditions are such that condensation might occur, and only when the generator is stationary.

The enclosure should be fitted with spring open – motor closing louvers and these should be closed as soon as possible after stopping of the machine, consistent with avoiding abnormal temperature built–up. All enclosure parts must either be galvanized or powder coated or painted with a salt–resisting paint to avoid corrosion and particular care must be taken with areas where moisture can be trapped.

It is vital that water that does enter the enclosure is not allowed to ”pond” under the alternator, as the air intake flow will give rise to turbulence beneath the machine and may allow water droplets, possibly contaminated with oil, fuel, coolant and salt to enter the machine. If water can lay under the alternator, consider inclusion of a baffle to prevent micro–droplets being drawn into the alternator air intake.

The following information has been extracted from a Generating Set canopy test programme and offers some practical data.

The test report confirmed the extent to which the insulation system of the generator will have lower Insulation Resistance [IR] values under conditions of high Relative Humidity [RH] %. The surprise was just how frequently the internal canopy RH% was above the prevailing ambient weather conditions.

The internal Generating Set canopy levels of RH are the result of an internal canopy microclimate, rather than the direct effects of the prevailing weather conditions. RH% was observed to be very high just after the working Generating Set had been stopped, even if the Generating Set had been run-on for engine temperature stabilisation after the load had been disconnected. Once the engine and generator stopped turning, the canopy internal air became static and the hot engine and generator components promoted the canopy internal micro-climate that resulted in heavy condensation droplets on the canopy walls and roof and so, very high RH%.

Before long, condensation formed on the generators wound components. This moisture mixed with winding surface contaminants combined to aid surface 'wetting' and caused the component to have low IR values. A generator fitted with dust filters directly to its air-inlet openings suffers badly when these filters become saturated with water [and salt] that has entered the canopy. These wet filters restrict the generators natural air circulation / ventilation and any air movement is likely to be wet air that has passed through these saturated filters.

Canopy design modifications were made to improve all aspects of ventilation. The air inlet opening was increased to ensure that the cooling air flowed at the lowest possible speed. The airflow through the inlet openings was made to turn through many 90º changes of direction and at each turn any airborne particle made to collide with the inlet metal work, effectively allowing only filtered air to finally enter the internal canopy.

One cause of high humidity levels present inside the canopy with the Generating Set at rest can be standing water inside a canopy with openings which are open to, or pointed in the direction of, prevailing weather conditions. The prevailing weather conditions can be somewhat controlled by openings with lots of 90º turns. The most common cause for high RH% levels is when a hot Generating Set has been suddenly stopped and then during the cooling down period, a micro-climate - dew point – situation develops within the canopy. The tests have been aimed at gaining a better understanding of the moisture situation and this has led to two distinct areas for consideration:

1. Control the moisture levels within the canopy by use of a space heating system under the automatic control of a fan powered heater that blows some 2kW of heat into the canopy internal space. This space heating system needs to be connected to a local mains supply or an adjacent running Generating Set.

2. Use a generator winding impregnation process able to provide an effective barrier to moisture & contamination penetration.

<u>In Service Considerations.</u>

The installed location of the Generating Set must be carefully considered to ensure that local working activities, local prevailing atmospheric conditions and sources of contamination are kept well away from the Generating Set's air-inlet openings.

Careful consideration must be afforded to: extreme seasonal weather conditions involving strong winds and heavy rain, sea mist and salt, sand storms, local manufacturing by-products and exhaust stacks from adjacent Generating Sets and vehicles.

<u>Partnership.</u>

The above is offered as initial design considerations for the alternator, Generating Set, and enclosure; therefore, a starting point for a joint operation between Cummins Generator Technologies and the Generating Set manufacturer, working towards equipment 'fit for purpose'.

It is must be accepted that there are many harsh environments, some instantly recognisable, others less obvious at the time of the initial enquiry, but very likely to result in a troublesome and shortened life for a standard Generating Set. It is suggested that with due consideration to the above detailed points a Generating Set destined for a harsh environment would be able to offer reduced operational service costs and a long life expectancy.