HIGH TEMPERATURE AIR CONDITIONING SYSTEMS USING AIR COOLED CONDENSING UNITS TO COOL MOTOR CONTROL CENTERS AND OTHER ELECTRICAL EQUIPMENT ROOMS DURING ABNORMAL CONDITIONS IN NUCLEAR POWER PLANTS.

Michael J. Fox
Engineered Environments, Inc.
Cincinnati, Ohio 45245

Abstract

Abnormally high temperatures can occur in equipment rooms in a Nuclear Power Plant during LOCA and HELB accidents resulting in ambient temperatures exceeding 120°F. Normal air conditioning systems are designed for ambient temperatures in the 95°F to 120°F range. Refrigerant compressors used in conditions above 120°F require special design considerations to prevent failure. This paper will identify the experiences learned from designing and manufacturing air conditioning equipment for use in desert warfare and how these techniques were applied to air conditioning equipment use in cooling a Motor Control Center (MCC) designed for high temperature applications with ambient conditions of 130-140°F.

I. Introduction

Using a military design modified for Nuclear Power application solved the problem of designing an air conditioner to cool a Motor Control Center (MCC) when exposed to LOCA conditions. Nuclear design conditions typically are not as severe as the military conditions except for temperature. The MCC room had limited access to additional power and no access to water for heat rejection. The resulting design required an air-cooled air conditioning unit capable of providing 24,000 Btu/hr of cooling with an ambient condensing temperature of 130°F.

Designing air conditioning equipment for high temperature applications is fairly common in industry, as in steel mills and chemical processing plants. These facilities provide access to water for condensing, allowing compressors to operate at conditions normally associated with air conditioning systems. However, when water is unavailable for heat rejection, the use of air-cooled condensing is required. This is a very common practice, most residential homes have an air condensing unit outside the home for heat rejection. These air conditioners are normally designed for ASHRAE conditions (95°F). But the more severe conditions are encountered in the design of air conditioning equipment located in the desert or for military applications. The military cannot depend on the availability of water and must design to the worst conditions found anyplace in the world.

II. Military Requirements

Air conditioning systems for military applications must be designed to handle severe conditions. Conditions may include extreme climatic, shock and vibration due to transport, and battlefield conditions, such as: radiological, biological, chemical, EMI, RFI, and HEMP requirements. Solutions to these complex problems require engineering expertise and manufacturing experience to provide cost effective equipment. The resulting design concepts provide systems that can operate at high ambient conditions (130°F), and survive high shock accelerations when mounted to mobile shelters. The design parameters of importance to a nuclear power plant are high temperature, radiation resistance, and seismic (shock and vibration) conditions.

III. Compare Military Equipment vs. Nuclear

The high ambient temperature required by military units often find similar requirements in Nuclear Power Plant applications where existing equipment is insufficient to provide cooling to equipment rooms. Many times the addition of heat producing equipment such as computers, fan and pump upgrades, or other electric items to the motor control center will result in the need for more cooling. In existing nuclear plants, the ability to provide cooling water either as chilled water for direct water to air heat exchanger or tower water for water cooled air conditioning is limited or none existent. The resulting condition is similar to what the military has prepared for in locations with high ambient conditions and no external water source.

The second similar requirement with military units is the need to provide cooling with minimal power demand. The military must bring the power source with them either as portable generators or batteries. The electrical demand for air conditioning is more than can be accomplished with batteries, so the use of gasoline or diesel fueled generators must be used. The design requirement for air conditioners with low power draw is similar to existing nuclear plants that cannot easily run new Class 1E service. In both cases the more electrically efficient the air conditioners operate the more versatile they become.

The third similar requirement with military units is the need to be rugged. The shock and vibration due to battlefield conditions or transportation of the equipment is technically more severe than the earthquake requirements in a Nuclear Plant. However, the design techniques required surviving any shock and vibration is similar. Again, the military units normally have no difficulty in meeting the response spectra found in Nuclear Plants, the difficulty is in the comparison of the existing testing to the requirements of IEEE 344. Most military air conditioning companies are not familiar with IEEE 344, but a few companies exist that have this experience.

The fourth similar requirement with military units is the quality assurance requirements. The requirement of 10CFR50 Appendix B for Nuclear Power Plants can be met with the equipment manufactured under Mil-I-45208 or Mil-Q-9858A. Again the distinctions between the QA programs are not familiar to most military companies, but can be resolved with little difficulty.

IV. Military Environmental Conditions from MIL-STD-210C

High Temperature: According the Mil-Standard the world's highest recorded temperature, 58°C (136°F) occurred at El Azizia, Libya on 13 September 1922. El Azizia is located in the northern Sahara at 32°32'N, 13°01'E, elevation 112 m. At least 30 years of observations are available for this station. Besides the 58°C reported, maximum temperatures of 56°C (133°F) and 53°C (127°F) for August and June have also been observed.

The hottest area of the world lies in the interior of northern Africa eastward to India. The hottest part of this area is the Sahara desert, which qualifies as the worst part of the world for high temperature. The hottest 1-, 5-, 10-percent temperatures are 49°C (120°F), 46°C (115°F), and 45°C (113°F), respectively.

Air conditioning for military use is required to be designed to operate in the hottest 1-percent temperature any place in the world during the warmest month of the year, then it must be designed for a diurnal cycle in which the air temperature attains a maximum of at least 49°C (120°F) at a height of about 1.5 m above the ground.

In addition, the military specifications also require equipment to operate in high temperatures that would be expected to occur at least once during 10, 30, and 60 years in the hottest part of the world. These temperatures are 53°C (128°F), 54°C (130°F), and 55°C (131°F) respectively. These values were derived from statistical analysis of 57 years of temperature data from Death Valley, CA and are considered representative of conditions in the Sahara desert.

Highest Dew Point: According to the Mil-Standard the highest accepted dew point observation is 34°C (93°F), recorded in July (exact date unknown) at Sharjah, Arabia, on the shore of the Persian Gulf. This corresponds to a mixing ratio of 35×10^3 PPM.

The long-term extreme occurrence of dew point is about 2°C more than the 1-percent value. This may not be as detrimental to equipment as a somewhat lower dew point occurring for an extended period of time. Therefore, the usual manner of determining long-term extremes is not followed for high absolute humidity. Rather, the long-term extreme will be a repetition of a daily cycle typical of a location experiencing high absolute humidities for extended periods of time.

Long periods with high absolute humidities were found at Belize City, Belize during August. The dew points found in coastal, moist tropical locations specified by military specification result in dew points between 26 and 28°C for ambient temperatures between 27 and 30°C.

High Relative Humidity with High Temperature: Relative humidity indicates the degree of saturation of the air. It is the ratio of the actual vapor pressure of the air to the saturation vapor pressure.

The maximum RH (not including supersaturation) of 100 percent is encountered in nature at temperatures up to about 30 to 32°C (86 to 90°F) right over water surfaces adjacent to coastal deserts. Over much of the world's tropical areas, 100 % RH temperatures up to 26°C (79°F) occurs quite frequently. RH of 100% is present in fog and clouds, but may also be present before fog is visible. One hundred percent RH is also closely approached in tropical jungles.

Surface relative humilities of 100% with fairly high temperatures are common in the moist tropics. An observed RH of 100% with temperature of 30C (86F) at Dobochura, Papua, New Guineas has undoubtedly occurred at other locations in the moist tropics.

V. Military Environmental Control Units (ECU)

The basic military ECU for this application was based on the MIL-STD-1408B, "Air Conditioners, Standard Family of Military Air Conditioners, General Application Characteristics."

This standard serves as a catalog of units comprising the standard family of military air conditioners. The standard family consists of 28 units ranging from 6,000 Btuh/4,500 Btuh heating to 60,000 Btuh cooling/47,000 Btuh heating. These units are arranged into six categories: compact vertical, compact horizontal, split-package, MPI's (multiple power input), 18,000 trailer mount, and 54,000 DEPMED (Deployable Medical Systems.) All units cool, dehumidify and heat. The heating capacity was designed so that the power demand in the heating mode approximates that of the cooling mode.

These units provide various features depending on their mission. Features of interest are:

- Rugged construction and able to withstand high levels of shock and vibration
- Automatically controlled cooling
- Self-protection against abnormal temperatures
- Self-protection against cutoff of condenser air flow
- Compatibility with sensitive electronic systems.
- A hot gas bypass control system enables precise air conditioning without cyclic disturbance of the external power supply circuit

VI. ECU for Nuclear Application

An existing Nuclear power plant needed to remove an additional 24,000 Btu/hr. from the Motor Control Center (MCC) without access to the chilled or service water system. The MCC was too far from an exterior wall to allow a typical split system air conditioner to be used. Instead a self-contained compact vertical ECU was used. This unit allowed the housing to be face mounted to a vertical wall. A cutout and through the wall duct provided the supply and return air directly to the evaporator section of the ECU. To save space the air conditioner was required to be wall mounted in the room adjacent to the MCC where the ambient temperature was 130°F. The evaporator section of the air conditioner would be in the conditioned space via the interconnection duct and "through the wall connection". The air returning to the evaporator would be 122°F. Normal air conditioning systems are designed for ambient temperatures in the 95°F to 120°F range. The equipment designer must be aware that a commercial unit may not be suitable for operation in an extreme environment. These conditions were perfect for a military type ECU specifically designed for desert/high ambient conditions.

VII. Design Considerations for High Ambients

In designing a high ambient system one must be aware of the physical limitations of the compressor. Most refrigeration oils will start to break down at temperatures around 350°F. As the cylinder temperatures approach 325°F, the lubricating oil will literally evaporate off the cylinder wall like water on a hot griddle. At these temperatures the ring and piston wear can be extreme. Normally discharge line temperatures within 6 inches of the compressor outlet will be 50F to 75F cooler than cylinder and piston temperatures. Therefore, most compressor manufacturers consider a discharge temperature of 275°F to be a failure temperature condition. Since the physical constraints on the compressor are fixed, the most critical area of unit design for high ambient temperatures is the condenser.

The higher the condensing pressure for a given evaporator pressure, the higher the compression ratio and the more critical the discharge temperature. In high ambient areas a direct flow of air over the compressor will help in maintaining acceptable oil temperatures. In this application the condenser was oversized by over 50% to reduce the compression ratio.

Another problem with designing either Military and Nuclear applications is the common problem of over designing the system based on load and high ambients for a small portion of the life of the equipment. More critical temperature conditions can occur when normal loads are seen for equipment designed for high ambients. Higher compression ratios created by high condensing temperatures and low evaporating temperatures occur at partial loads. These higher compression ratios raise the discharge temperature. This is a common occurrence in Nuclear Power Plants because of over conservatism in the design load calculations. In military applications the same piece of equipment has to work both in the desert and in the more temperate climates. In order to meet this requirement the addition of a Hot Gas Bypass circuit is typically added to the evaporator inlet. This bypass has the effect of creating an artificial cooling load. This creates another problem, high return gas temperatures.

To solve the potential high return gas problem partially due to adding Hot Gas Bypass, the addition of a Desuperheating valve (also known as liquid injection) was added to the suction line between the evaporator and the compressor. This provides the necessary injection of liquid to help reduce the temperature of the refrigerant gas returning to the compressor within allowable limits. The desuperheating valve should be of adequate size to reduce the temperature of the discharge gas to the proper level under maximum bypass conditions.

The last problem to consider is the balance of all these seeming simple fixes to allow the compressor to operate at its design envelope edge without failure. The size and location of all the refrigerant components is critical for the proper operation of the system. The design information available from the component manufacturer may not address the limits of the component because of both legal and proprietary considerations. Therefore, the manufacturer of the high temperature air conditioner must have intimate knowledge of the selected components.

VIII. Final Design

In this case the ECU was designed with oversized condenser coil and evaporator coil normally sized at 36,000 Btu/hr. for this 24,000 Btu/hr. application. The compressor was also capable of providing 36,000 Btu/hr. The refrigerant system included hot gas with side port injection into the distributor, liquid injection (desuperheating), head pressure control, filters/driers, receiver, and line sizing to allow this system operator properly. After normal assembly and testing the ECU was placed in the environmental chamber and subjected to 130°F ambient on the condensing side and 122°F on the evaporator. In order to keep the compressor temperature within its upper limits the hot gas was set at 58 psig (to prevent icing at low loads) and the desuperheating valve was adjusted as required. With oversized components the system would tend to work at its upper load limits. This would bring the compressor temperatures to critical design temperatures. In order to help prevent over heating, the thermal expansion valve was sized with the proper orifice to prevent excessive amount of refrigerant from entering the evaporator. After adjustments for the high temperature application was successfully completed the ECU was tested at lower temperature (ASHRAE) conditions to verify the equipment would operate a normal conditions.

IX. Conclusion

The ultimate design criteria for air conditioning equipment is still temperature dependent. In the 120°F to 130°F range, equipment can be designed and successfully operated. As the temperature approaches 135°F to 140°F material limits prevent the successfully design and operation of air-cooled equipment. It is important to remember that at higher temperatures the margins for equipment failure may only be a few degrees.

Individual testing of components and experience as part of previous designs allow the air conditioner designer to become a successful system integrator. In the case of nuclear or military use the First Article of each design or design change is required to be thoroughly tested to specific testing requirements. These test subjects the equipment to many hours of severe testing before the design concept is acceptable. The successful completion of this type of equipment has largely been left to the specialty companies with the years of experience to design and test equipment for high ambient conditions.