WET COMPRESSIO N SYSTEM

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WET COMPRESSION SYSTEM

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FOR DEMANDING APPLICATIONS

Wet Compression Technology

Wet Compression is a reliable and proven method of injecting water into the gas turbine inlet. Wet Compression is perfectly suited for upgrading peak load gas turbines.

Providing peak power enables electricity producers to react to increased grid power demand, i.e. during summer peaks or grid fluctuations driven by renewable energy sources leading to increases in customer revenues at high peak load electricity prices. Wet Compression is designed to increase the power output by injecting water into the compressor inlet, hence inter-cooling the compressor, reducing the compressor inlet temperature and increasing mass flow throughout the gas turbine. A power increase due to Wet Compression of up to 15 -20 % of the dry gas turbine base load power could be measured.

Wet Compression provides peak power on demand with a higher efficiency level compared to other “stand by” generators or simple cycle diesel applications, consequently carbon and nitrogen emissions can be reduced or avoided. The mutual occurrence of high ambient temperatures and increased peak load electricity demand make Wet Compression economically more beneficial and valuable.

Wet Compression Process Description

Wet compression is a process in which small water droplets are injected into the compressor inlet air in a proportion higher than that required to fully saturate the air. As the air gets heated during work of compression, the "excess" moisture is absorbed by the air in subsequent compressor stages. Since it takes less energy to compress relatively cooler air, there is reduction in compressor work. A reduction in compressor work directly translates to increase in net turbine output since one-half to two-thirds of a turbine output is used to drive the compressor.

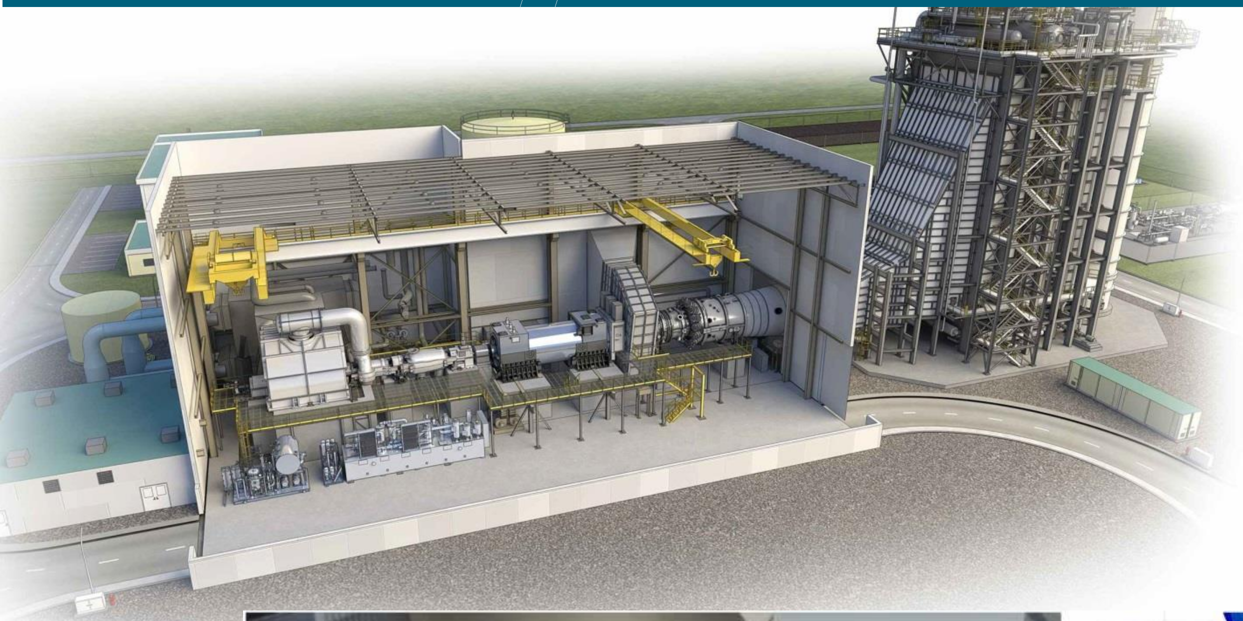
Another important contributor to increasing the turbine capacity as a result of wet compression is the ability to fire more fuel in the combustor, without raising the firing temperature. Because of the evaporative process in the compressor stages there is a reduction in the compressor discharge temperature. A lower entering temperature in the combustor allows more fuel to be added without raising the firing temperature. This is the reason why wet compression has also been occasionally utilized to reduce the firing temperature in cases where firing temperatures of units without wet compression systems in service have caused concerns with turbine component life and increased maintenance.

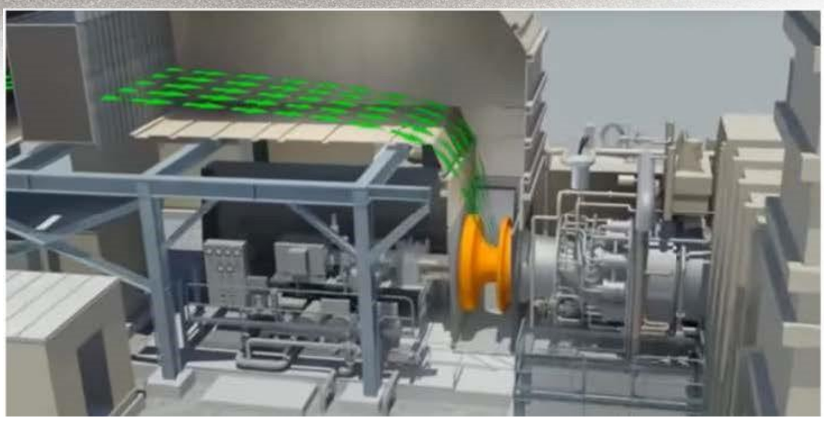
The third factor that contributes to increase in turbine capacity is due to increase in mass flow rate as a result of water spray and increased fuel flow, since turbine output is directly proportional to the mass flow rate.

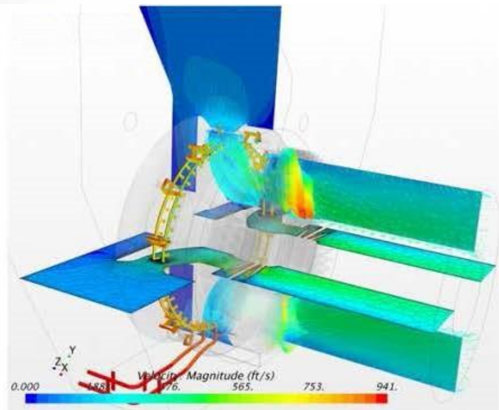
Unlike common systems for compressor inlet cooling like Fogging or Evaporative Cooler, Wet Compression not only cools down the compressor inlet temperature but is used as a compressor intercooling system. Therefore the main target of Wet Compression is to get fine water droplets well distributed into the compressor where they evaporate gradually.

The significant power increase of Wet Compression mainly consists of 3 different effects.

Compressor intercooling	Due to the evaporation inside the compressor the necessary work for the compression of the cooled air and therefore the compressor power consumption is reduced.
Inlet cooling	Although this is not the main target Wet Compression still achieves an inlet cooling effect as droplets evaporate on their way into the compressor. With cooling down the inlet air additional air mass flow enters the gas turbine.
Turbine power/mass flow increase	The turbine power output is increased by following factors: • Increased air mass flow due to inlet cooling, • Additional water mass flow, • Additional air mass flow by reducing the mass flow limitation of the first compressor stages by additional cooling and • Higher fuel flow







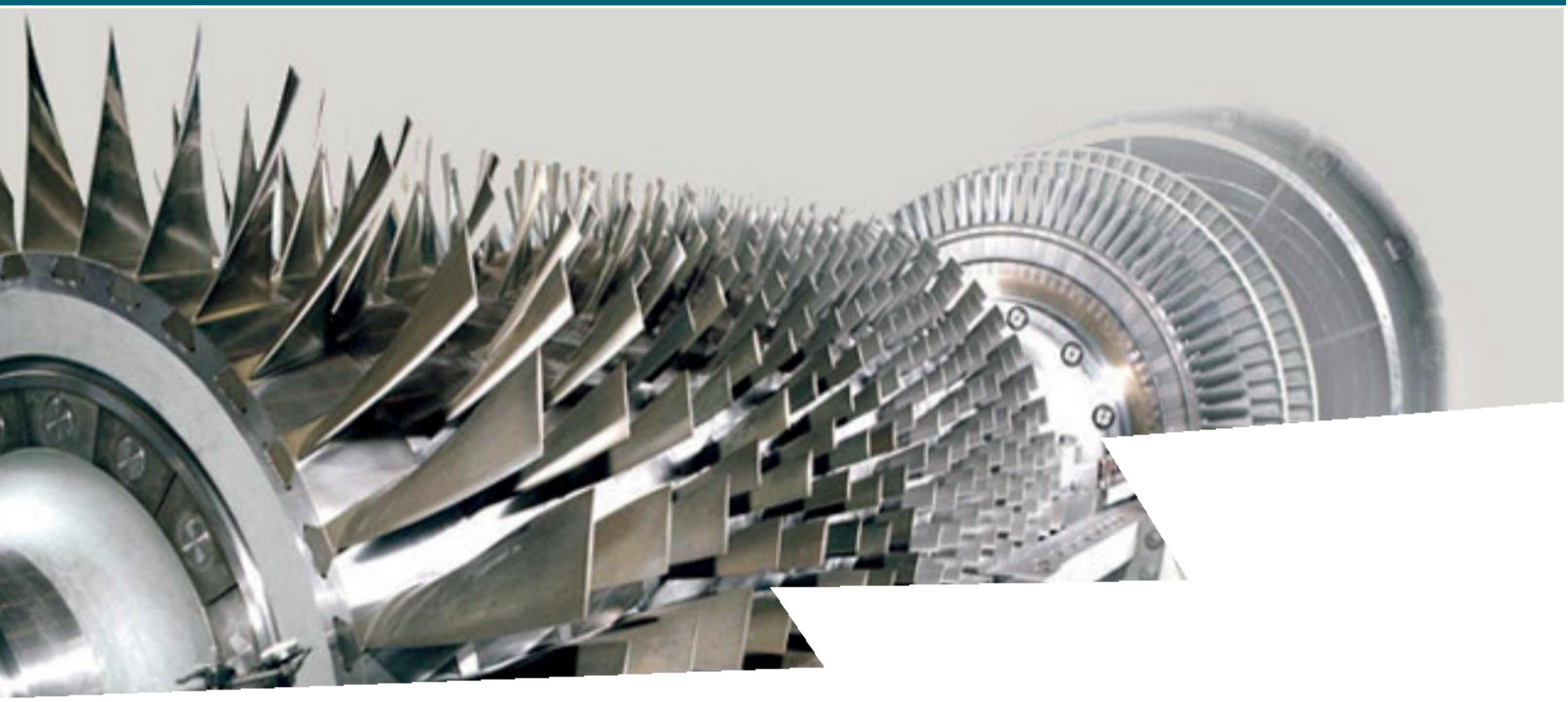
Wet Compression operating conditions

Wet Compression could be used as a flexible peak load system with easily adjustable power output. Only a few preconditions for Wet Compression are necessary for safe operation.

Wet Compression can be operated at compressor inlet temperatures >10 °C. The risk of ice formation on the compressor blades and consequential damages while operating at lower temperatures is too high and consequently prevented in the DCS control settings.

Wet Compression is started from base load with an initial mass flow of 2 or 2.5 kg/s which is also the minimum mass flow. Up to the maximum mass flow Wet Compression can be adjusted in a step less manner. The gradients for the water mass flow increase are limited to keep thermostresses for the gas turbine components at a low level; consequently the maximum performance is reached after nominally 18 minutes.

Wet Compression can be operated without respect to ambient humidity; even the combined operation with an evaporative cooler would be possible.



POWER GENERATION – %15-20 HIGHER EFFICIENCY

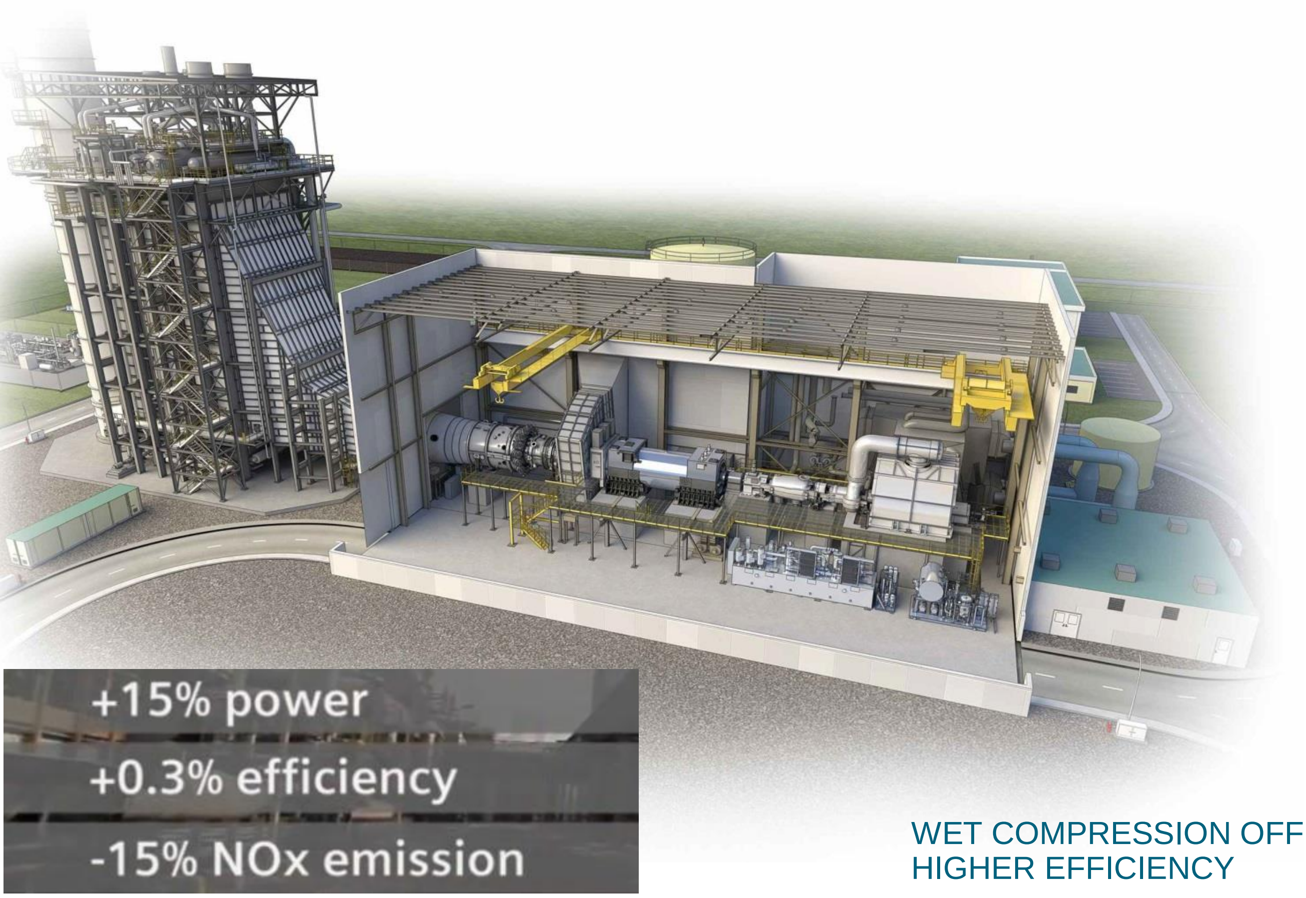
Performance Comparisons

The most commonly used power augmentation technologies for gas turbines are evaporative cooling (inlet fogging), wet compression, mechanical chilling (with or without thermal energy storage), and steam or water injection. Two other viable methods which have been applied on a limited basis so far are supercharging and humid air injection. A comparison of the various methods is shown in the table below. For the steam injection system, a combined cycle plant is assumed although the concept can be applied to simple cycle as well, but this will translate into an increased cost for a boiler.
The ambient conditions are assumed to be:
1) a dry bulb temperature of 35ºC with 50% relatively humidity,
2) a dry bulb temperature of 24ºC with 70% relative humidity, and
3) a dry bulb temperature of 15ºC with 60% relative humidity.

These conditions translate to a wet bulb temperature of 26ºC, 20ºC and 10ºC. It is worth noting here that the gains by the relatively inexpensive methods are somewhat limited by the ambient conditions. For example, the gain realized by fogging is dependent upon the difference between the ambient dry bulb and wet bulb temperatures as illustrated by the incremental power gains at points two and three. However, the gains by wet compression are more consistent over a wider range of ambient conditions. The same gains can be realized as long as the ambient wet bulb temperature stays above 10ºC. This can have a significant impact on the payback because it increases the MWhr gain throughout the year considerably.
As a result, the payback for wet compression system can be one-quarter or one-half of that for a chilling system. However they are complimentary systems and both can be applied to optimize gains.

COMPARISON OF POWER AUGMENTATION TECHNOLOGIES

Method	Evaporative Cooling	Fogging	Wet Compression	Chilling	Steam/ Water Injection	Humid Air Injection
Compressor Inlet Air Temp (ºC)	27	26	26	10	35	35
Output Increment (%)	5%	6%	15-20%	11%	6%-12%	8-15%
Heat Rate Improvement (%)	1%	1%	1-3%	-2% to 2%	-4% to –5%	-2% to -4%
Installed Cost ($/kW)	80-110	45-80	150-180	1000-1150	150 – 200 if steam source is available	180-250
Plant Integration	Inlet duct / silencing system treatment, Cooler design coordinated with inlet air system to minimize carryover, water supply and drains	Inlet duct / silencing system treatment (coating, lining, drains), Nozzle placement. De-ionized water supply & drains	Inlet duct treatment, control system integration for combustion and emergency response, cooling system modification, rotor grounding (all included in above pricing) De-ionized water supply & drains	Coil integration with inlet air system, Cooling tower and makeup water required, chilling units to be installed.	Combustion system hardware and software changes may be required. Steam or water supply	Humid air manifold to be added to CT, control logic integration required for upset conditions and base load firing temperature control, Cooling tower, HRSG and compressor trains to be added.
Maintenance	Low pressure pump, sump cleanliness, and periodic media replacement (approximately every 6 years)	Pumps, valves, nozzles and inlet system. Comp-ressor blades if carryover is excessive	Pumps, valves, nozzles.	Mechanical chillers, inlet coils and cooling tower. Similar to operating CT in a cold climate	Increased hot part metal temperature unless firing temperature is reduced. Compressor train, HRSG, and cooling tower	Increased hot part metal temperature s unless firing temperature is reduced



WET COMPRESSION OFFERS HIGHER EFFICIENCY

Out of all the available technologies, wet compression offers the most in terms of performance gains, heat rate improvement, reduction in emissions, and ease of installation at a relatively modest cost. Unlike evaporative cooling or chilling, the gains are not restrictive at lower ambient temperatures as long as the ambient wet bulb stays above 10°C. The technique of wet compression is very promising because of quicker payback. For example, the payback is less than half that of a chilling system.

Since this early application of Wet Compression and the experience gained from it, Wet Compression has been successfully applied to more than 80 units. These units include; GE Frame 6B, LM2500PE, Alstom GT-24, Alstom GT-26, Siemens Power Generation W501D5, W501D5A, W501FC, V84.2. While there are concerns with the application of wet compression, if applied correctly it has been shown to reduce NOx, improve heat rate, and is a reliable source of additional power regardless of ambient conditions.

Wet compression technology is a turbine inlet cooling and compressor intercooling system that has been successfully demonstrated on aeroderivitive, mature and advanced combustion turbines. This technology has shown that with proper application it is the most reliable means of power augmentation that reduces NOx emissions, and improves heat rate and is not ambient temperature dependent like other turbine inlet cooling technologies.

Wet Compression has influence on different parameters in the gas turbine and combined cycle process. The main influences can be described as follows:

Parameter	Change by Wet Compression
Gas turbine power output	▲
Gas turbine efficiency	▲
Gas turbine outlet temperature	▼
Fuel mass flow	▲
Exhaust gas energy	▲
NO_x - emissions	▼
Combined cycle power output	▲
Combined cycle efficiency	▼

▲ Increase ▼ Decrease

ENGINEERING SERVICES AT A GLANCE

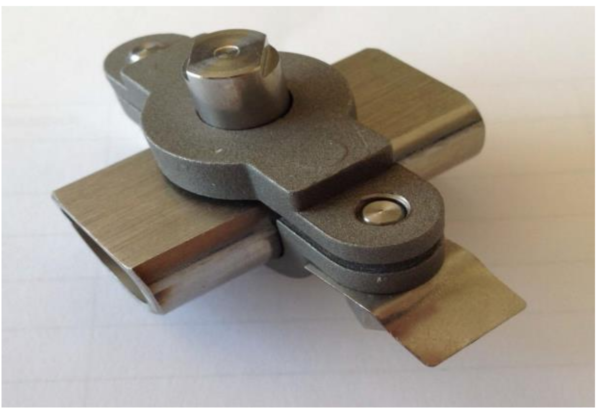
Construction:

- New construction
- Replacements
- Retrofit of steel and concrete filter housings
- Upgraded filter solutions

Components:

- Single- or multi-stage filter walls
- Weather hood constructions
- Weather louvres
- Measuring instruments
- Infrared anti-icing systems
- By-pass flaps
- Heat exchanger
- Air ventilation ducts
- Air cooling systems
- Droplet separators
- Fans
- Transition ducts and elbows
- Electrical equipment
- Shut-off louvres
- Silencers
- Support construction
- Insulation

Wet Compression Compananents



Wet Compression Companents

Wet Compression Companents

Wet Compression Companents Description

Wet Compression technology is the most cost effective and currently specified power enhancement technology for gas turbines. The concept consists in applying cooling to the air feeding of the gas turbine compressor. Demineralised water is injected into the intake airflow in the form of a fog of fine water droplets <5 micron for the nozzles installed.

Our solution to the Wet Compression installation foresees the positioning of the nozzle arrays between the air intake duct and expansion joint before the compressor.

The Wet Compression Systems has carefully taken into account the specific gas turbine air intake arrangement for the design of the proposed fogging solution. The following equipment applies to Wet Compression unit to be installed as proposed for one gas turbine.

Description	Quantity x each GT
Pump skid	1
Water filter plus a manual shut-off valves	3 (1 micron)
Demin water counter	1
Piping feeding line to demin water/filter	1 for max. 3 m.
High pressure pumps and motors	5
Piping feeding lines to nozzle array/ Headers	5 for max 35 m. each
Nozzle banks diam. 1" INOX 316 L	54 = m 2.0
Number of nozzles INOX 316 L	1127
Program Logic Controller (with hardware Siemens) cabinet	1
MCC cabinet	1
Inverters in MCC cabinet	5
Metering instruments for compressor inlet air (temperature, relative humidity and Venturi pipe)	1
Water pressure reducer	1

All components in contact with demin water are made of AISI 316L as per Wet CompressionSystems standard design requirements.

Wet Compression Companents Description

Pump Skid Components

Unit system will be provided complete upon a floor skid dedicated to the gas turbine, with sizing made as compact as practical while allowing for adequate maintenance needs

The skid will include:

- One flow meter with transmitter for the total water flow
- Three water filters with cartridge 1 µm, complete of pressure transmitter
- Five high-pressure pumps directly coupled with electric motor , each one equipped with:

  On the suction and discharge side:

  - a manual shut-off valve to interrupt the feeding if necessary;
  - an on/off electric solenoid valve to intercept automatically the water when the pump is on stand-by mode;
  - a glycerine bath manometer required to check the local feeding pressure;
  - a minimum safety pressure sensor, interfaced with the control system;
  - flexible rubber pipe with internal teflon to avoid the transmission of pump/pipeline vibrations;
  - a glycerine bath manometer to check the local operating pressure;
  - a manifold unique divided in half for low and high pressure
  - a pressure regulating valve, set to the maximum allowable pressure level;
  - an accumulator to compensate the micro vibrations produced by the alternative pumps;
  - a maximum/minimum pressure sensor, required to guarantee the range of operation pressures;
  - drainage valve, for discharge water.

Pump bypassing:

- Each pump can be bypassed or isolated in the event that repairs are necessary to any one stage.

Water induction protection:

- The Wet Compression System will have a sensing capability such that any increase in water flow due to a damaged or missing nozzle will provide an alarm and will automatically shutdown the related pumping stage.

- This protection system ensures the limitation of uncontrolled water flow containing large droplets of water that could be injected into the turbine compressor inlet

Piping and fittings

Piping connecting the pumping skid to the nozzle array headers is made in AISI 316 L stainless steel diameter pipe 1"½. The piping will be laid on AISI 316L stainless steel conduits.
Piping connections on the pumping skid are made by high-pressure rubber and internally coated with Teflon, fittings in AISI 316 L stainless steel hose.

Nozzle Array

The nozzle array is made of the following elements:

- Headers are stainless steel pipes, having the required length in relation with the air intake geometry and "T" parts to be connected to the nozzle banks.
- Nozzle banks are realized with pipe stainless steel, nominal diameter 1'' and thickness 2,87 mm. with constant pitch perforation for the head multi-nozzles, the distance between holes is 120/100 mm.
- The nozzle has with 65 bar a water flow rate of 22.0 l/h and 30.7 l/h at 123 bar.

The nozzles are connected to the water supply pipe with stainless steel wire.

Turbine air integrity is guaranteed at all times. All non-welded and non-integral attachments including nuts, bolts, threaded nozzles, support brackets, etc. are tack-welded or have a backup integrity device constituted of a stainless steel clips to prevent compressor FOD risk.

Most parts of nozzle arrays will be preassembled before being fitted into the air intake structure.
Headers and nozzle banks will be bolted to the support frame inside the air intake structure and tack-welded.

Supporting Frame

The supporting frame of the nozzle array inside the intake is made by AISI 316 L. The fastening of the frame coupling points occurs by means of stainless steel bolts with tack welding.

Pumps

Five high-pressure piston pumps will be installed to achieve the maximum fogging capacity of gas turbine.

All the pumps are connected to an inverter and will have variable speed drive capabilities to enable flow control (operating pressure between 65 and 123 bars).

The pump skid is preassembled at the factory before shipment.

The pump skid will be bolted on the existing concrete slab close to the air intake, at location confirmed and will be equipped with motor controllers complete of motor heating and temperature transmitter, power supply junction box and signals junction box.

Program Logic Controller (PLC)

- The process connects gradually the pumps required for the attainment of the freely prescribed power gain in relation with signals arriving from the GT
- During a spray unit connection phase: in the first place the motorized valve located on pipe feeding the spray unit is opened, a timer counts a set time before starting the minimum pressure gauges safety devices placed on suction and on discharge side then it activates the relevant alternative pump.
- The pumps rated revolutions, connected by the controller, are modulated by inverter;
- The signal that controls the inverter increases in relation to the value of variance desired power augmentation.
- The pumps connected with the inverter operate at least according to the minimum working rate imposed by the inverter itself (for instance 60%), the controller modulates the remaining field.
- In consequence of the effects produced by the minimum operation rate, the controller checks the maximum cooling effect which may results before connecting a pump. If the step passage between two pumps exceeds the desired set-point, the software logic limits the start-up of the pump.
- The controller settles how many pumps have to be connected and to which frequency value (Hz) the pumps modulated by inverter have to operate. The different commands are sent to the electrical switchboard, which activates the pumps, according to the circumstances.

Program Logic Controller (PLC) Cabinet

Steel sheet casing (IP55) including a human-machine interface (HMI), the PLC and its extension (analogical and digital I/O), equipped with Touch Panel for local operation.

The PLC will be connected to the DCS by MODBUS, thus enabling the operating room to control the functions and the parameters.

The PLC SIEMENS series S7-ET200S with includes a software programme for automatic control (number of pumps in operation, control of the inverters, quantity of water injected for each pump and total water consumption).

The controller will be programmed to obtain a linear flow rate over the entire operating flow range.

Electric Switchboard (MCC)

Steel sheet casing with built-in protective motor switch, inverters, including protected internal wiring. Hand switches, main interrupter as well as Volt and Amperometer and signal set into front door. The switchboard will be constructed in accordance with CE standards for outdoor conditions (IP55).

The PLC cabinet and the MCC cabinet will be delivered assembled ready to be connected. The MCC cabinet includes the inverters.

Pump skid motor power supplies and instrumentation signals will be connected on-site from the skid junction boxes to the PLC and MCC cabinets.

Inverters

Fogging units have the ability to linearly control the water flow pumped to the nozzle array over the entire operating range.
Frequency converters will be used to adjust the water flow for all pumps.

Connection to the air intake walls

Installation of the support frames requires bolting or/and welding of the support frame beams on the air intake duct walls.

Nameplate

A corrosion resistant metal nameplate will be permanently attached to the major components and will include the following information:

- PO Number
- Equipment Item Number
- Supplier's Name
- Serial Number
- Rated Capacity
- Size and Type KKS numbering, as per P&ID example in annexure E will be used for labelling the major components.

Battery limits

The following battery limits shall be considered:

i. Power Supply:
   a. The customer will provide and will install the power supply cable to the electrical switchboard.
   b. Connection lines between PLC cabinet and MCC cabinet will be supplied and installed by customer.

ii. Control & gas turbine signals:
   a. At Fogging Systems PLC connection point for the gas turbine signals and the fogging system field instrumentation (pump skid signals junction box) will be supplied and installed by customer.

iii. Demineralised water and piping connection
   a. within 3 meters of pumps skid
   b. Connection pipe between skid and air intake (nozzle arrays) max. 35 m.