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Title: IR Suppression – Exhaust Gas Cooling by Water Injection

Abstract:

This paper describes a comprehensive system for cooling the hot engine exhaust systems on a modern warship, to achieve a low infrared signature.

The key to the system is an advanced hybrid Eductor/Diffuser system which combines passive cooling air entrainment with active water injection. This permits very low exhaust gas exit temperatures without the associated high engine back pressure.

Introduction

Davis Engineering Limited (DAVIS) has been active in the field of infrared (IR) signature management (analysis and suppression) for more than twenty years. During that same period, the IR guided anti-ship missile has proven itself an effective weapon, and continues to develop in complexity and capability.

Most modern naval ships include some form of signature suppression to reduce the ship susceptibility to IR threats. The newest generation of imaging missiles will have increased capability in the identification and lock-on of their targets, and will require increased attention to signature management.

New ship designs must include detailed signature management studies and the result is increasingly sophisticated IR suppression systems, for both the engine exhausts and the solar-heating of the ship's surface. This paper describes a new comprehensive exhaust cooling system for the MEKO A100.

IR Signature Suppression

A ship's IR signature is made up of internally generated sources, solar heating and background signature.

We are concerned here with the signature caused by the hot engine exhaust, and its heating of the ship's surfaces. Both the propulsion engines and electric generating engines must be addressed. The exhaust gases can be extremely hot (400 - 500°C), resulting in very hot uptake metal (300-400°C) and very hot exhaust plumes.

Based on many years of experience of IR suppression of ships it has been concluded that most IR suppression schemes can be organized into a four level system. The basic levels are:

i) no suppression (baseline platform);
ii) basic cooling of visible exhaust duct metal, and skin cooling with available means (NBC water wash);
iii) exhaust duct cooling, plume cooling to 250 ^{o}C, and skin cooling with available means; and
iv) duct cooling, plume cooling to 150 ^{o}C, full skin cooling (with dedicated water wash for skin cooling).

The final selection of level depends on the perceived threat and on the system cost. Most modern naval ships tend to opt for level ii) or iii). Several ships currently in the design stage use level iv).
The ultimate effectiveness of an IR suppression system can be measured in terms of reduced IR susceptibility. This can be done using well established analysis tools such as the NTCS code. Confidence in codes like this are increasing as validation with sea trials testing matures. The analysis presented in this paper was done using NTCS. Further details on this code can be found in the references listed at the end of this paper.

Figure 1 shows how the various levels of IRSS affect the platform susceptibility and the effectiveness of active IRCM. With analysis tools like NTCS it is possible to predict the benefits or IRSS in terms of the time available to use IRCM. This ability to quantify benefits in these terms gives more meaning to the cost-benefit analysis.

These increased levels of protection must be offset against back pressure limits on the ship's engines. One method to achieve these low plume temperatures while not imposing unacceptable losses on the engines is to inject sea water into the engine exhaust in order to cool it. While water-injected marine exhausts are comparatively common for smaller diesel exhausts, they are not frequently used on larger vertical gas turbine exhausts. DAVIS, in conjunction with Blohm & Voss (B&V), has developed such a system for the gas turbine exhaust on the MEKO A100 frigate.

In addition to the direct benefits of lowering the IR signature by hot metal and plume cooling, any region (ie, masts) that the plume may impinge are also cooled. The wild heat load in machinery and internal spaces is greatly reduced while the system is operating and the back pressure is reduced.

The System

The water injection system developed for the MEKO A100 is a hybrid air/water eductor/diffuser system. A schematic is shown in Figure 2. The DAVIS Eductor/Diffuser IR suppressor is a passive suppression system that draws in cooling air in order to cool visible metal and the plume. Normally, increasing the back pressure of the device is necessary in order to improve performance. However, in the case of the hybrid water-injection system, sea water is introduced through a multi-stage arrangement of nozzles in order to achieve further plume and metal cooling. Special drains and catchments are used to collect excess water and direct it out of the ship as wastewater. The nozzles and pipes automatically drain to eliminate any concern about pipes freezing in unheated sections of the vessel. Corrosion-resistant material (ie, high-nickel alloys) are used in the wetted areas to extend the operational life of components exposed to hot brine.

The nozzles may be activated in various stages in order to control the amount of water introduced and match it to either ambient environmental conditions, or engine power settings. This helps to minimize water usage and also minimize the visible fog that will result in the exhaust plume as it leaves the ship. The nozzle staging is computer-controlled in order to provide appropriate plume-cooling as a function of engine power state. A fresh-water purge cycle is also available on demand.

A similar system has also been developed for the diesel engines, using a combination of vertical and horizontal exhaust paths. These two independent flow paths give the operators flexibility under different operating situations. The vertical path may be used when dockside or under certain sea states. The horizontal exhaust is equipped with staged water injection, similar to that on the vertical GT exhaust. A diverter valve is used to switch between the two exhaust paths.

Unique Features

While water injection marine exhausts are comparatively common, the implementation of such a hybrid system on a large, vertical gas turbine exhaust is novel. Due to this, it provides a number of unique benefits:

1. The system provides moderate, passive IR signature reduction without the requirement for water injection. At the same time, there is only a very small back pressure (ie, fuel) penalty associated with this protection level.

2. If the highest level of IR protection is deemed necessary, the water injection can be added with no additional back pressure penalty. Only a comparatively small pump is required to supply sufficient water for plume and metal cooling. This is much superior than requiring large, high powered fans to force more air into an air-cooled IRSS.

3. The staged nozzles match water flow to the engine conditions so that waste water is minimized. The nozzles are configured so as to minimize or eliminate salt build up on the interior of the ducts in places where the wetted surface dries out. The nozzle staging is computer-controlled and may be manually adjusted. There is a further “low fog” setting that allows the ship to minimize the visible “steam” signature in the plume, at the cost of slightly less IR protection.

4. A “three-way” valve is also supplied in order to allow the system to be manually switched between sea water and fresh water. This is to allow the nozzles to be purged of salt and soot prior to extended shut down. This purging is important in reducing the maintenance requirements and extending the life of the system, while keeping fresh water demand at a minimum.

Performance

The addition of sea water to the exhaust plume can achieve temperatures that would require 5 times the static back pressure for a typical passive IR suppressor. This has major implications for fuel consumption, as the majority of most ships' operational lives are spent in a low-threat environment. Even in the event that the water injection is turned on (ie, a real or potential IR threat is present), the only additional penalty imposed is the power required to run the water pump. This power consumption is extremely modest compared with the output of the gas turbine, and when compared to the loss experienced by even a small back pressure increase. This is the primary performance benefit from water injection.

The effect on the IR signature is dramatic. Studies conducted at DAVIS have shown that plume temperatures below 100°C can be achieved. A typical comparison between a hybrid water system and a passive air only system is shown in Figure 3. In addition to plume cooling, metal heating is virtually eliminated from the exhaust. Figure 4 shows actual 3-5 m IR footage from water tests. Note that the "hot" spots shown in the bottom of the frame in all pictures is a heated calibration plate. All hot metal virtually disappears as water is added.

Control

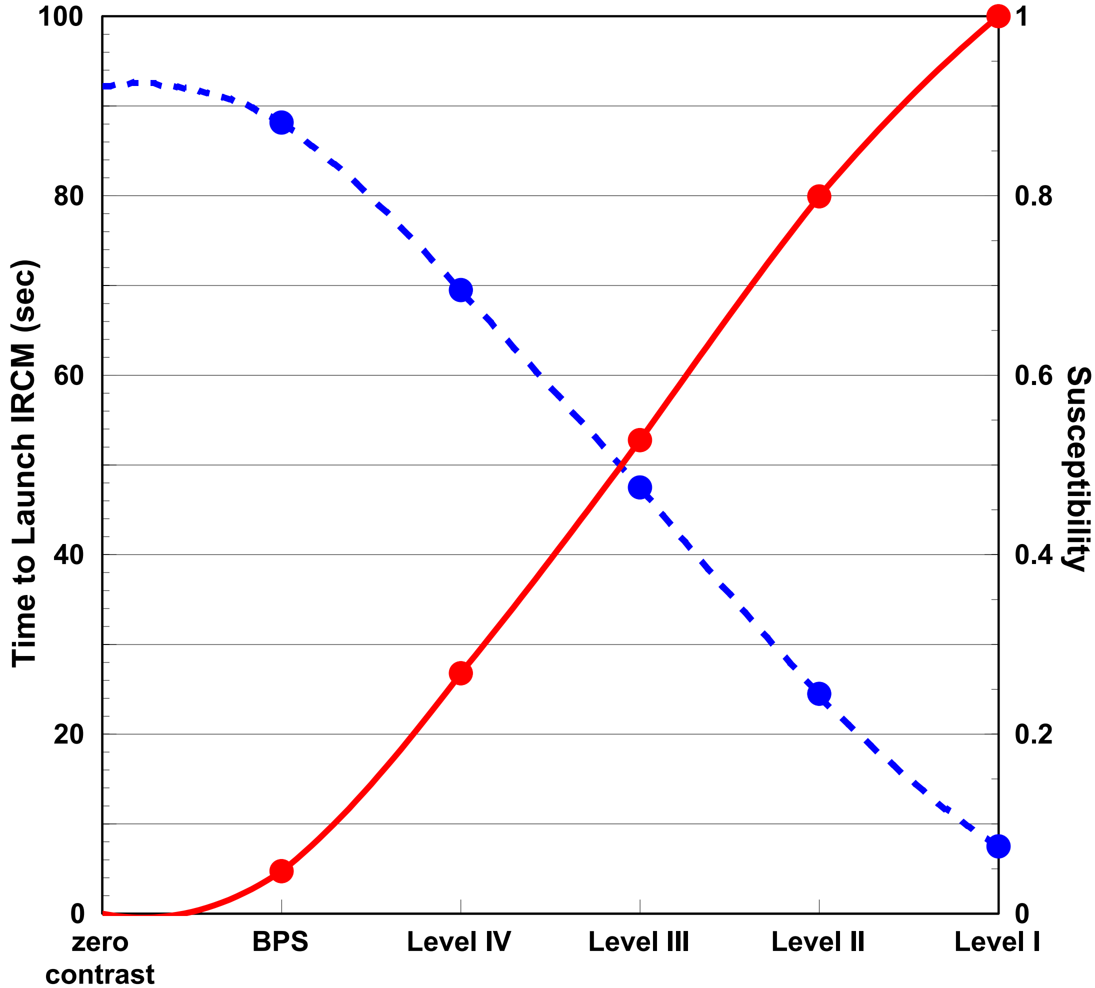
As discussed above, the system is computer-controlled from two redundant PLC devices located in the forward and aft machinery spaces. This ensures that the system will function in the event of software/hardware failures or physical damage. Water flow rates are modulated through different combinations of "stages", with each stage having a set (and different) flow rate. This allows for the control valves to be simple ON/OFF devices, but still to achieve a comparatively fine control over water flow. This is then matched to the engine exhaust flow and controlled from the throttle settings. The function of the system is automatic, but all features may be overridden manually.

If a completely automatic control is desired, this is possible through the combination of the hybrid water injection system with DAVIS' Onboard Signature Manager (OSM) software. This application collects real time data from around the ship and assesses the overall level of IR "exposure" at any given time. Countermeasures can then be actuated automatically (ie, water injection or even a hull water-wash in order to reduce the contribution of solar heating) based on a threat level determined by the operators.

The ability for the operators to simply input the level of IR threat into OSM and then allow the program to manage the signature is a powerful tool. It restores the advantages of a passive system (you do not have to expend resources actively managing the systems); but has the advantages of active IR suppression systems: if you don't need the extra level of suppression, you don't have to turn it on, and therefore pay for it.

Conclusions

The development of the hybrid water injection system by DAVIS and B&V for the MEKO A100 marks a new level of IR protection for warships. The system combines a variable IR signature, which may be adapted to the threat environment, with a low back pressure penalty on the engine. When combined with other features of the MEKO A100 exhaust systems, it makes for an unique design which will be able to meet new developments in IR threats for years to come.



- Assume IRST detects threat at 27-28 km range
- Assume threat flies at 300 m/s

Figure 1: Real World Impact of IRSS

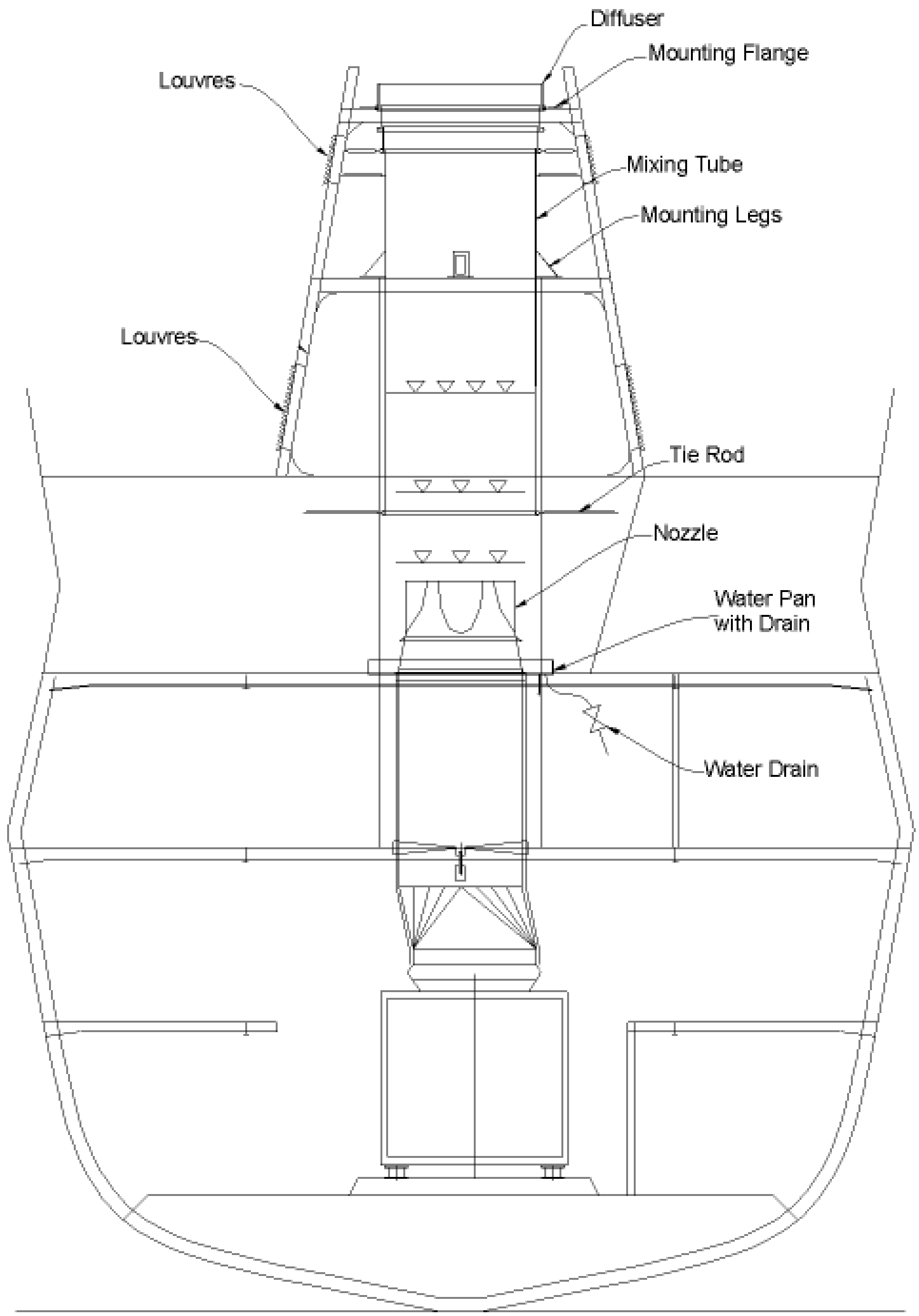


Figure 2: Schematic of Hybrid Water Injection System

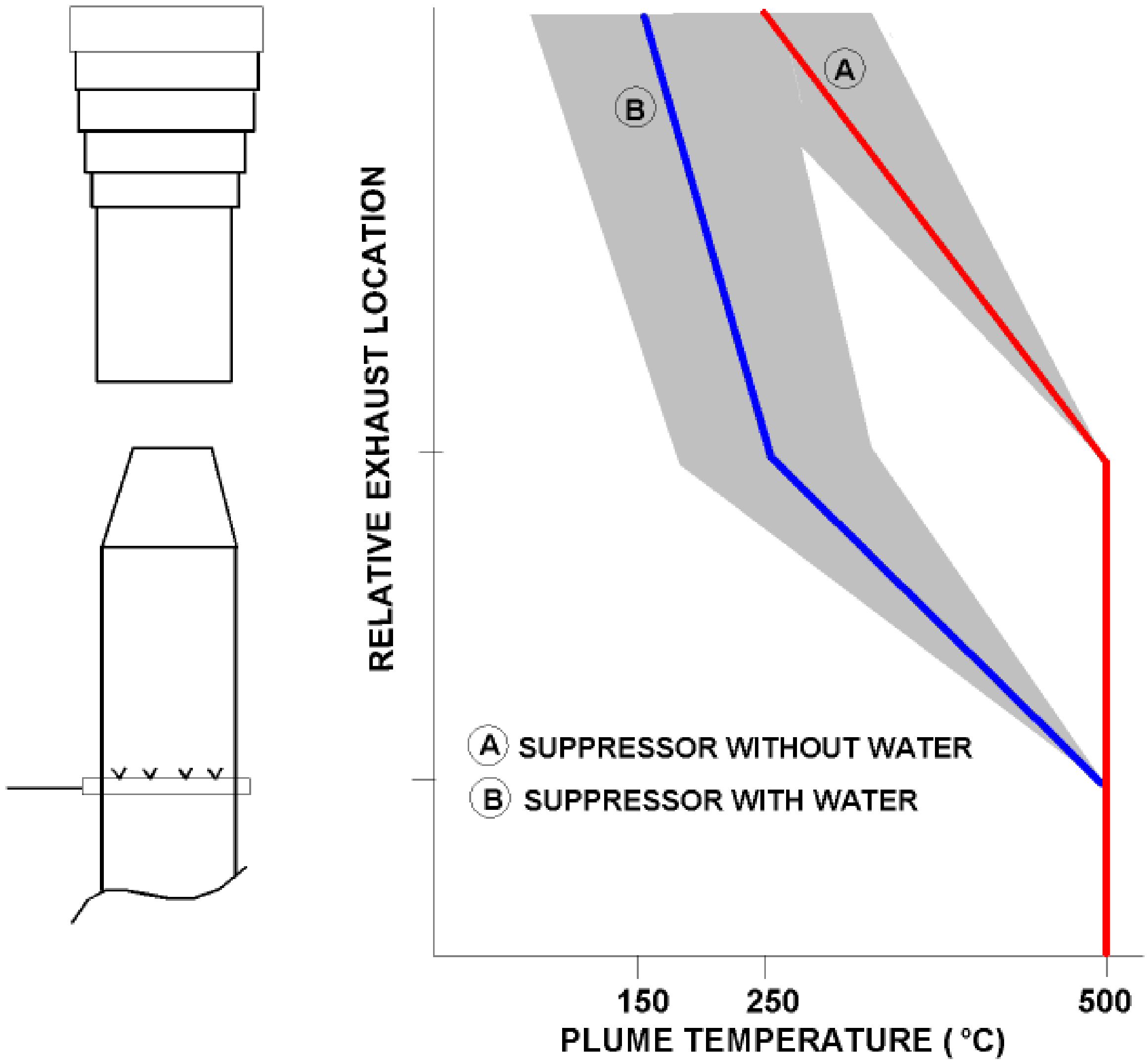


Figure 3: Typical Plume Temperature of Hybrid Water Injection System

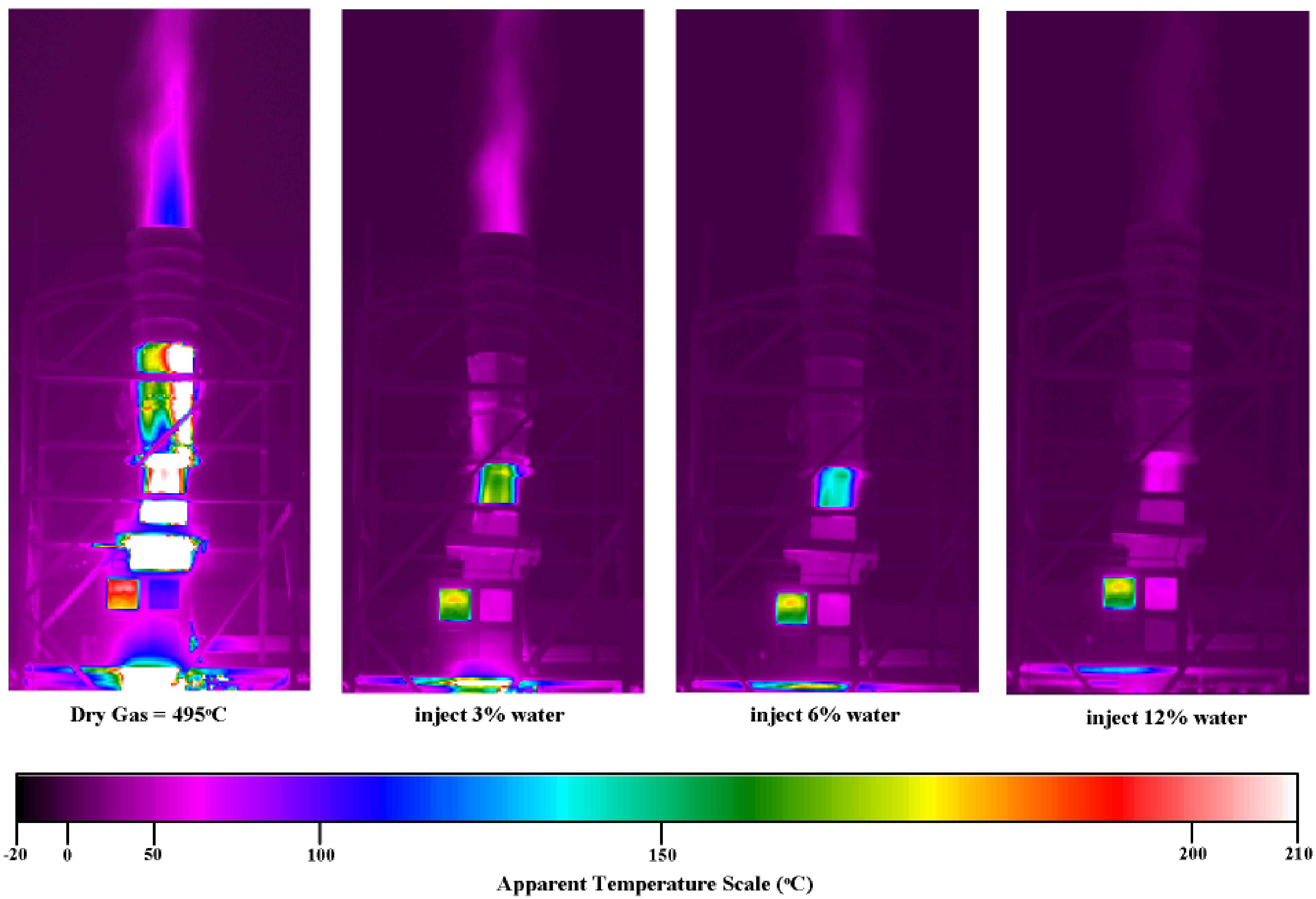


Figure 4: Infrared Images of Prototype Hybrid System