Humid Air Motor
Technology for green profits
Adding Ecology to Economy

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In recent years, global and local regulations covering exhaust gas emissions from heavy duty medium speed diesel engines have become progressively more stringent. They cover all applications i.e. power generation and propulsion systems on land and at sea. In particular, emissions of oxides of nitrogen (NOx) have become a major issue.

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In general today, modern marine diesel engines are capable of meeting the requirements of the first and second stages of the MARPOL 73/78 Annex VI regulations – commonly called IMO Tiers I and II – using only on-engine and in-cylinder modifications. On the 1st January 2016, however, the NOx limitation of IMO Tier III will come into force and is so stringent that additional devices will be needed (see figure 1).

Moreover, there are already regional regulation such as those in Norway and Sweden which reward every kg of NOx not emitted. In response to these regulations, ship owners have an incentive to adopt NOx reduction systems on their fleets.

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**H₂O against NOₓ**

It is well known that the cooling effect of water can prevent NOₓ formation during the combustion process. Well proven methods employing water to reduce NOₓ are fuel-water emulsification and humidification of inlet air (HAM principle).

**HAM principle**

Over 90% of NOₓ formation results from combustion temperature peaks. The principle of HAM is to humidify the inlet air in order to lower these temperature peaks. The HAM system humidifier produces saturated air.

The ability of water to decrease the formation of NOₓ is exploited in the same way as with fuel water emulsification, but the quantity of water added is much higher and the heat for water vaporisation is taken from the compressed air after the turbocharger or other engine-related heat sources.

When the water vapour is mixed with the compressed charge air, two mechanisms can be identified:

- Increase of the specific heat capacity of the mixture
- Dilution of the charge air: water vapour replaces air

The quantity of water (in g/kg dry air) which can be injected into the inlet air depends on the temperature and the pressure of the mixture.

As shown in the diagram in figure 3, when the air temperature rises so does the quantity of water it is possible to vaporise.

In this area HAM has an outstanding advantage, since it uses the heat of the engine to bring the saltwater up to temperature. No external energy source is needed. In addition to the heat of the charge air after the turbocharger, in many applications heat from the engine coolant and exhaust gases can be introduced into the charge-air to increase its capacity to absorb moisture.

With the HAM method a NOₓ reduction level of 40% is achievable without using additional heating of the intake air and a level of 65% when additional heat is introduced from the engine coolant or exhaust gases.
How HAM works

The functional principle of HAM is quite simple. Figure 4 illustrates the HAM Process:

1. Filtered saltwater is pumped to the catch tank to replace evaporated and purged loop water.
2. The HAM system itself cycles water in a loop between the catch tank and the Humidification tower ("HAM vessel").
3. A heat exchanger between the catch tank and the HAM vessel heats the saltwater using an on-engine heat source.
4. Three injection stages spray the heated saltwater into the charge air.
5. At the same time the compressed charge air from the exhaust turbocharger bypasses the charge air cooler and is piped into the HAM vessel air inlet. Flowing through the HAM vessel, the charge air absorbs the water. Due to the high loop capacity of the water all particles (incl. salt) fall back into the catch tank and, over a certain salinity level, are purged. Thus no salt from the saltwater can enter the engine.
6. To avoid tiny droplets reaching the combustion chamber, the humidified charge air passes through a high-performance mist catcher at the end of the humidification tower.
7. This humidification leads to saturated charge air which is fed into the engine.

Proven in Practice

To prove the theoretical results of HAM technology, field tests under real conditions were carried out.

Marine

Viking Line took the decision to equip all four engines aboard its vessel “Mariella” with the HAM system. This car ferry crosses daily between Helsinki and Stockholm. The main characteristics of the vessel are:

- Length: 177 m, Breadth: 29 m, Weight: 37,800 t
- 2200 passengers, 540 vehicles
- 4 engines: 12 PC2-6.2 each rated 5,750 kW at 500 rpm

The system was installed on main engine number one in July 1999 (all engines were subsequently equipped with HAM) and since then it has been operating with seawater. The installation was carried out without interrupting vessel operation.

One of Viking Line’s requirements was to be able to switch from the standard intake air system with charge air cooler to HAM with the engine running. This requirement was met by using butterfly valves.

The ship-owner now considers that this condition is no longer required since the charge air cooler is no longer necessary. In case of emergency, without HAM and without charge air cooling, it has been verified that available power is still 50% to 60%. System installation in the engine room is illustrated in figure 5.
Since July 1999 the systems have logged about 100,000 operating hours without any major problems. The following list presents the results over that time:

- Low operating & maintenance costs confirmed
- Extended service intervals
- No trace of water in lube oil
- Decreased lube oil consumption
- No corrosion
- Cleaner engine (deposits are “washed” away)
- Decrease of cylinder and valve temperatures

Stationary

On Corsica, one PC3 engine (12 MW) was equipped with HAM to test it under power plant conditions. The following data are available on this configuration:

- Specific fresh water consumption: 410 g/kWh

The following results were confirmed during the test:

- \( \Delta \text{NO}_x = -65\% \) is confirmed
- 650 mg/Nm³ \( \text{CO} \) limit

Marine applications

Viking Line, M/S Mariella
- Passenger ferry
- S.E.M.T. Pielstick 4x12VPC 2.6 HFO
- 5.7 MW per engine
- 68% emissions reduction

Nyholmen AS M/V Kvannoy
- Purser Trailer
- MAN 1X 16V28/32A MDO 3.9 MW
- 62% emissions reduction

Plant applications

Electricité De France, Lucciana plant
- Power Plant
- S.E.M.T. Pielstick 1x 18VPC3 HFO
- 12 MW
- 65% emissions reduction

Diesel United, Japan, Tohoku Plant
- Power Plant
- S.E.M.T. Pielstick 1X 12VPC4.2 HFO
- 10.4 MW
- 45% emissions reduction
(60% before modifications of engine parameters)
Conclusion

To meet the challenge of reducing oxides of nitrogen during diesel engine combustion, the HAM system is an efficient solution with the following advantages:

Efficient NOx reduction
The targeted NOx reduction of 65% was confirmed during HAM usage on the car ferry “Mariella” and a power station on Corsica.

Very low operating costs
Seawater may be used as the consumable for the HAM system, meaning operating costs are very low. The use of an additive to prevent calcium deposit does not significantly increase operating costs. The heat to vapourise the water can be taken from on-engine sources i.e. engine coolant and exhaust gases, without affecting the ship’s overall energy recovery levels. Even with no additional input of heat, a NOx reduction level of 40% is achieved at nominal load.

Best practice to fulfill regulations from an economic standpoint
All three case studies showed that under the specific conditions of existing regulations, and taking account of the balance of investment to operating costs, HAM always demonstrated extremely short amortisation periods.

Engine operation optimisation
Addition of water vapour to the charge air has a beneficial effect:

- Exhaust gas temperatures and valve temperatures are lower, leading to a decrease in thermal loading.

Simple operation
The use of HAM is simple as shown by experience on the “Mariella”:

- Simultaneous start for both HAM and engine.
- 15 minutes before stopping the engine: engine at idle speed and water circulation shut off in order to dry the air system.

System reliability
The system is intrinsically self-controlled without any need of a load-related control loop. The system is stable and responsive.

- Longevity: Even after 100,000 hours of operation, HAM has demonstrated consistently high effectiveness in NOx reduction.
- Stable: No abrupt changes in engine operating parameters if water circulation is shut-off.
- Responsive: Favourable response to load variations.

The HAM system is thus an economically and ecologically viable way to effectively reduce NOx while optimising engine operation.