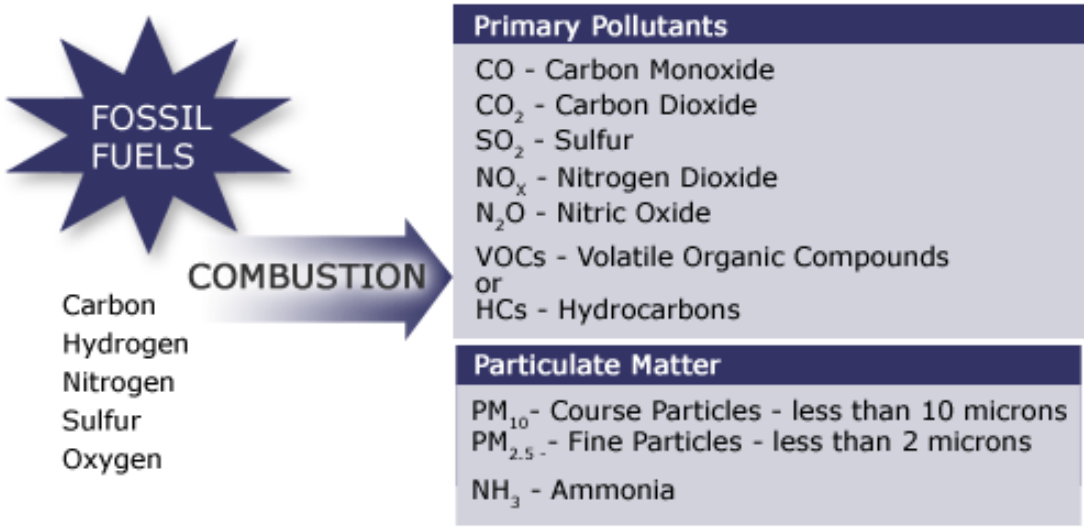
Novel advancements in fuel emulsification of Heavy Fuel Oils (HFO)

SulNOx Group PLC with their unique emulsification product have teamed up with SciMed Ltd and Hielscher Ultrasuond GmbH to bring a novel solution to one of the biggest environmental issues facing our planet today.

The current problem of combusting HFO

HFO combustion for heavy industry is coming under increasing scrutiny from environmental and governmental pressure. This is particularly true of the power generation and shipping industries which often rely on HFO as a primary source of energy. However, age-old tried and tested methods of chucking HFO into burners has a serious problem. When not enough oxygen can combine with a hydrocarbon fuel during combustion the result is incomplete combustion. This is currently occurring in heavy engines combusting HFO resulting in waste comprising of both undesirable emissions and unspent HFO. Current methodology to increase oxygen by blowing air over the combustion chamber is inadequate.



Combustion of HFO:

$CH_4 + 2\ O_2 + N_2 + H_2S \rightarrow 2\ H_2O + CO_2 + CO + NO + NO_2 + SO_2 + Energy$

Resulting formation of acid rain:

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$OH + SO_2 \rightarrow HOSO_2$

$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$

$SO_3 + H_2O \rightarrow \mathbf{H_2SO_4}$

Resulting formation of nitric acid (HNO_3) a component of acid rain:

$H_2O + N_2 + NO_2 \rightarrow HNO_3 + HNO_2$

$3\ HNO_2 \rightarrow HNO_3 + 2\ NO + H_2O$ & $4NO + 3\ O_2 + 2\ H_2O \rightarrow \mathbf{HNO_3}$

The 21st century is on a relentless drive to reduce waste, pollutants and harmful emissions.

IMO 2020 is the International Maritime Organization's ruling that from 1 January 2020, there must a be significant reduction of marine emissions in international waters.

One solution to this problem is to improve the burn profile by increasing the oxygen availability. The current methods of blowing air over the burners to increase oxygen availability clearly is not helping enough as the fuel ratio of HFO in these engines is still too "rich" which causes production of soot and black particulate matter which has been linked with serious human health issues.

Ideal Stoichiometry

$$C_3H_8(g) + 5\ O_2(g) \xrightarrow{\Delta} 3\ CO_2(g) + 4\ H_2O(g) + \text{energy}$$

Too 'rich' (not enough oxygen – too much fuel)

$$C_3H_8(g) + 3\ O_2(g) \xrightarrow{\Delta} CO\ (g) + 4\ H_2O(g) + \text{energy}$$

$$C_3H_8(g) + 2\ O_2(g) \rightarrow 3\ C\ (g) + 4\ H_2O(g) + \text{energy}$$

SOOT

Our combined technologies and vision to deliver one solution.

In collaboration with SulNOx Group PLC, SciMed Ltd have devised a novel emulsification method using ultrasound devices and SulNOx's proprietary emulsification agent which produces stable HFO emulsions which can then be combusted totally cleanly when compared to both other HFO and even diesel fuels. We are proposing to change the combustion profile as follows:

Current method:

INPUT: HFO combustion.

OUTPUT: Energy, SOx, NOx, PM / Soot → Post combustion cleaning

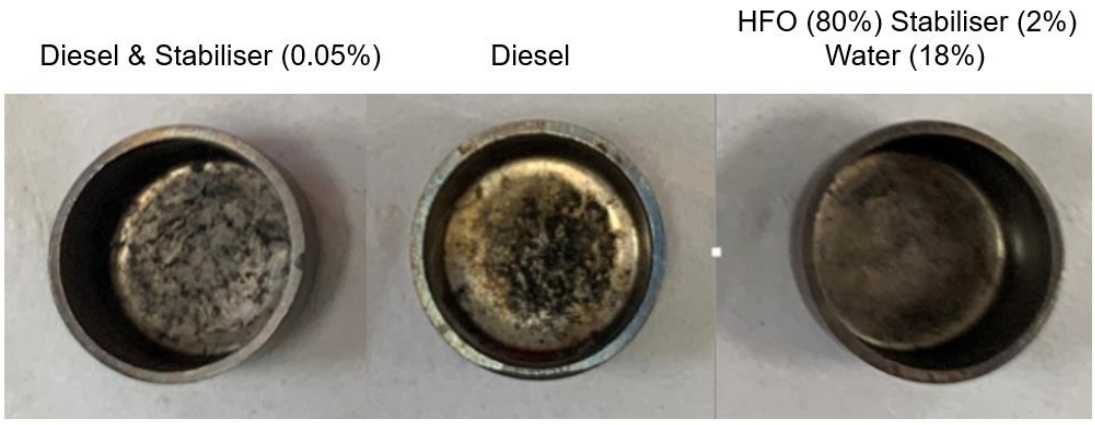
Ultrasound emulsion method:

INPUT: 80% HFO + 2% SulNOx Stabiliser + 18% water & Ultrasound → HFO emulsion

OUTPUT: Energy, reduced SOx, reduced NOx, Greatly reduced PM / Soot. → Minimal post combustion cleaning.

Lab testing at SciMed Ltd as proof to ASTM standards.

Viscometer and Calorific Value (CV) testing on HFO emulsified with water using ultrasound and SulNOx's emulsification product was completed in our labs. CV combustions were conducted in an ideal environment meaning an oxygen rich atmosphere of 30 bar ensuring complete combustion. (A Parr 6200CLEF calorimeter was used for this.) In a real-world situation, such as a power station of large ship engine, you are likely to see less than complete combustion for the pure 100% HFO fuel and particulate matter / soot (PM) would be produced giving a lower CV liberated. In this oxygen rich test environment all samples burnt perfectly cleanly, so no PM was produced. So please bear that in mind when comparing to the 100% HFO sample at 43.4 MJ/Kg as this is not a real-world energy result but is artificially high. Incredibly, we compared this HFO emulsion to regular diesel from a UK forecourt and found that the combustion of the HFO was actually cleaner and left less particulate matter than the diesel that you would regularly put in your car! This shows a dramatic improvement in burn profile and waste material generated when HFO is combusted as an emulsion due to increased oxygen availability for the fuel.



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Also please note the temperature. 16.5 deg C, so these were not heated up but done cold so after heating viscosity would be even less.

Sample composition. (Emulsification agent / Water / HFO)	Viscosity (cP)	Energy (MJ/kg)
3.1. (0/0/100)	151,500	43.4090
4.1. (2/8/90)	157,000	39.6854
5.1. (3/18/80)	61,500	35.5150
6.1. (5/28/70)	49,500	32.0719
7.1. 6/38/60)	35,800	24.0124

There is very little change in viscosity with the addition of 10% water (4.1) even though there is the expected drop in total energy. However, an additional extra 10% water, which is what we consider to be our "sweet spot" for emulsification, there is a significant drop in viscosity by over 60% (5.1). The energy drop is also less significant which means this should be the perfect spot for highest energy output (due to clean burning from emulsification) when balanced with a significant drop in viscosity and also a minimal outlay of money to invest in ultrasound equipment (see later). As the water content goes up, the viscosity drops further but not to the same degree (6.1. & 7.1). The cliff edge is going from 10% (4.1) to 20% (5.1). And it is also significant that the energy input required (i.e. ultrasound energy and costs) increases dramatically going from 20 to 30% water.

Previous analysis of the emulsifying process and the amount of ultrasound power required for complete emulsification to produce a stable fuel product has shown that the amount of emulsification agent present has a direct effect on how much energy is required. In general, the more emulsification agent used, the less ultrasound power is required. This is represented by specific energy, Ws/g (Power, per second per gram of material being emulsified).

1% emulsification agent, 19% water, 80% HFO = 61.3 Ws/g of ultrasound energy

1.5% emulsification agent, 18.5% water, 80% HFO = 25 Ws/g of ultrasound energy

2% emulsification agent, 18% water, 80% HFO – 8 Ws/g of ultrasound energy

In other words, you need 7.5 times more ultrasound power when you drop from 2% to 1%, and thus the CAPEX costs for the ultrasound go up, from approximately £49K per ton per hour, to £387K per ton per hour from our original studies. Naturally you will eventually make that money back by spending less on emulsification agent though. But you can see why we tend to recommend 2% as the formula starting point.

HFO (g)	Stabiliser (g)	Water (g)	Water /Emul (%)	Temp degC	Power (Ws per g)	Kw H/t	Using 12KW tons/h	12KW = £271K Hardware cost for 1 T/h
80	1	5	7%	70-75	31.4	9	1.33	£204 K
80	1	9	10%	70-75	42.8	12	1	£271 K
80	1	18	19%	70-75	61.3	17	0.7	£387 K
80	2	18	20%	70-75	8	2.2	5.5	£49 K
4	0.03	2	33.60%	65-75	108	30	0.4	£678 K

Also, you can see here that there is no sign of any water dropping out of solution over the following two days and we can declare that is a completely stable emulsion which was kept at ambient temperature.

Further tests have already been conducted on large lorries and agricultural machinery looking at emulsifying diesel and plans are being drawn up for trials on a large ship running HFO engines to observe the real world benefits of this system. We anticipate:

- Very significant reduction of $PM_{2.5}$ and PM_{10} production means longer service intervals and less wear and tear on parts → Less engine down time → Cost Savings.
- Reduction in Total Mass of HFO being consumed → fuel savings → Cost Savings.
- Compliance with new regulations such as IMO 2020 and improved environmental profile.

Additionally, the drop in viscosity and stable nature of the HFO emulsion also opens up new opportunities in both storage and the possibility of pumping and transport of HFO over long distances in pipelines.

Our recommendations for suitable HFO emulsion systems are below. However, please remember, these systems can be used for so much more than just HFO. All sorts of fuels can successfully be emulsified.

If you would like to discuss this further or other possible fuel emulsification solutions and systems then please contact either SulNOx Group PLC or SciMed.

Dr D A Clarke

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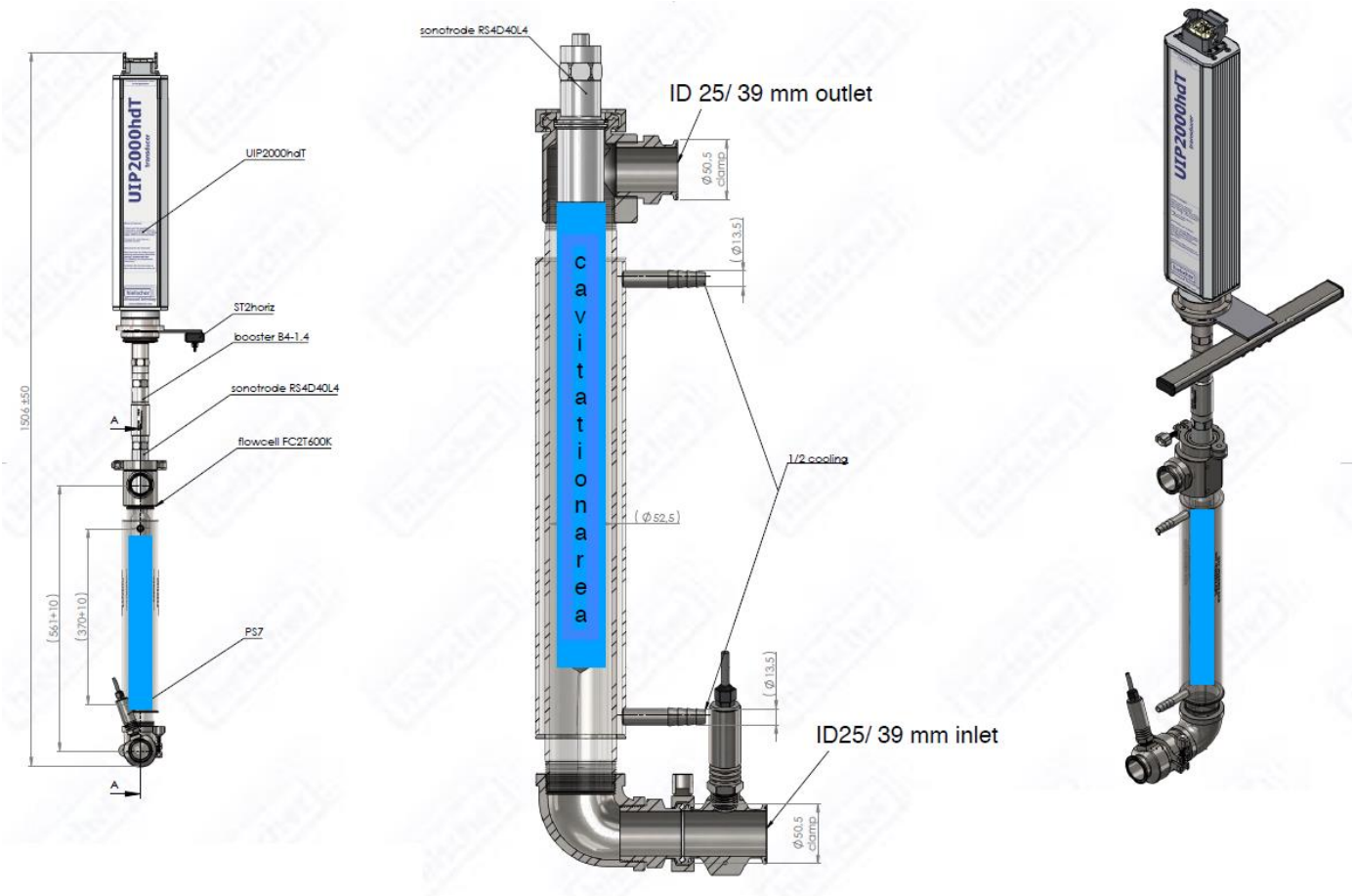
Recommendations for emulsification systems.

2 x 2 KW system for 2% emulsion, 1500L/h.

This is a straightforward system with 2 x 2KW units in series for use with the 2% emulsification agent system. We will supply the transducers, generators, cascatrode, flow cell, a basic stand holder and amplitude boosters. This is suitable for production of up to 1500 L/h of emulsified fuel. There is no sound protection cabinet here, but if you want to build one or want us to make one then let me know. Essentially this is the bare bones and you will require your own expertise and engineers to integrate this and represents the minimum costs from us to you.

TOTAL COST = $85,000.00 (approx. USD)



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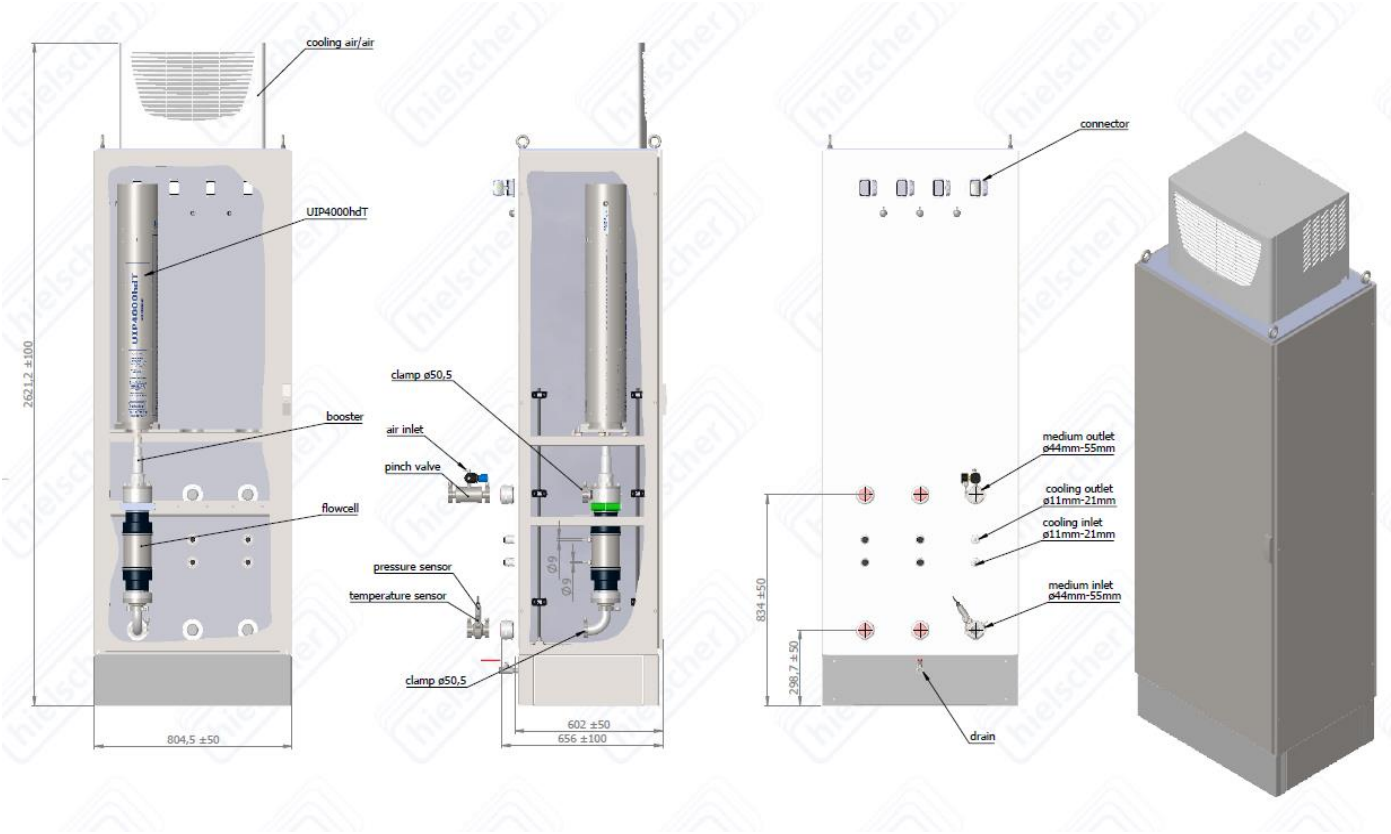
Larger 3 x 4KW system for 1.5% emulsion, 1500L/h.

As mentioned above, the reduction to 1.5% emulsion is very possible. The emulsion formed is stable and the power input required is a modest step up from the 2 x 2 KW system above. Essentially we are tripling the required energy (from 8Ws/g to 25 Ws/g), so we need to triple the size of the ultrasound set up. This is a much more complete system here which rather than being made from 2KW systems, we have the luxury of stepping up to the big boy, the 4KW system and we are putting 3 of these in a row. It comes in a completely integrated self-contained cabinet and means less expense and engineering work from your side to integrate it. Please see the attached schematic which shows the sound protection cabinet (for both the generator and transducer) with 1 x 4KW system hanging in it. Imagine we put three in here and you connect them in series.

TOTAL COST = $245,000.00 (approx. USD)



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