FURTHER EVALUATION OF WATERMIST FOR THE ROYAL NAVY

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ABSTRACT

In 1993 the Royal Navy's firefighting section, ME225, instigated a programme of work to research the principles of water mist and develop its application as a possible replacement for halon in warship machinery spaces. Since that time the programme has progressed from initial experiments to examine the interaction between mist and flame, through trials in an unenclosed rig designed to investigate 'zoned' protection', tofurther tests with the rig enclosed. The earlier work was covered by a paper presented at the 1996 conference[2]. The latest phase of work has involved two projects. At the Loss Prevention Council, trials have been carried out with the aim of identifying the capabilities and limitations of typical high and low pressure watermist systems against small 'difficult' fires in a strictly controlled environment. A separate programme of trials was conducted at the Fire Research Station and involved a selection of low and high pressure nozzles, a range of typical naval fuels and various fire obstruction scenarios. This phase has involved enclosing the original rig to enable the nozzles to act in a 'totalflood' manner while also allowing the simulation of typical ventilation characteristics for a scaled down machinery compartment in both the normal and damaged conditions.

INTRODUCTION

The Royal Navy uses halon 1211 and 1301 in primary fire extinguishing systems on over 100 vessels including surface warships, Royal Fleet Auxiliaries and some submarines. Following the ban on halon production by the Montreal Protocol, ME225 has been researching alternatives as replacements for existing equipments and for specification in future designs. It is of primary importance that such systems do not compromise the fire fighting effectiveness currently afforded by halon or introduce unacceptable safety risks when used. Support to current, essential use halon systems is from a halon bank.

BACKGROUND

The assessment of halon alternatives has concentrated on the *two* areas considered most appropriate for warship compartment protection; gaseous agents and watermist systems. With many of the range of current chemical alternatives there are increasing concerns over: toxicity, environmental implications, inability to remove heat from hot surfaces and importantly the potential to release significant quantities of toxic combustion breakdown products. This final point has serious implications in a warship, where compartments must be re-occupied and become operational again as soon as possible. It is for these reasons that our main area of research and development continues to be watermist. The best of these systems have good potential to satisfy all of the above criteria while offering effective firefighting performance.

SCOPE OF TRIALS

Two parallel series of trials have been performed to investigate different aspects of watermist performance. The first involved a joint venture between ourselves and the Technical Development Group of the Loss

Prevention Council. The second was a continuation of earlier work with the Building Research Establishment's Fire Research Station. At the LPC, the highly controlled environment of the test compartment has allowed strictly controlled but relatively small scale trials. At the FRS, trials *can* be camed out with relatively large fires and the flexibility of the rig has allowed different obstruction and ventilation scenarios to be tested.

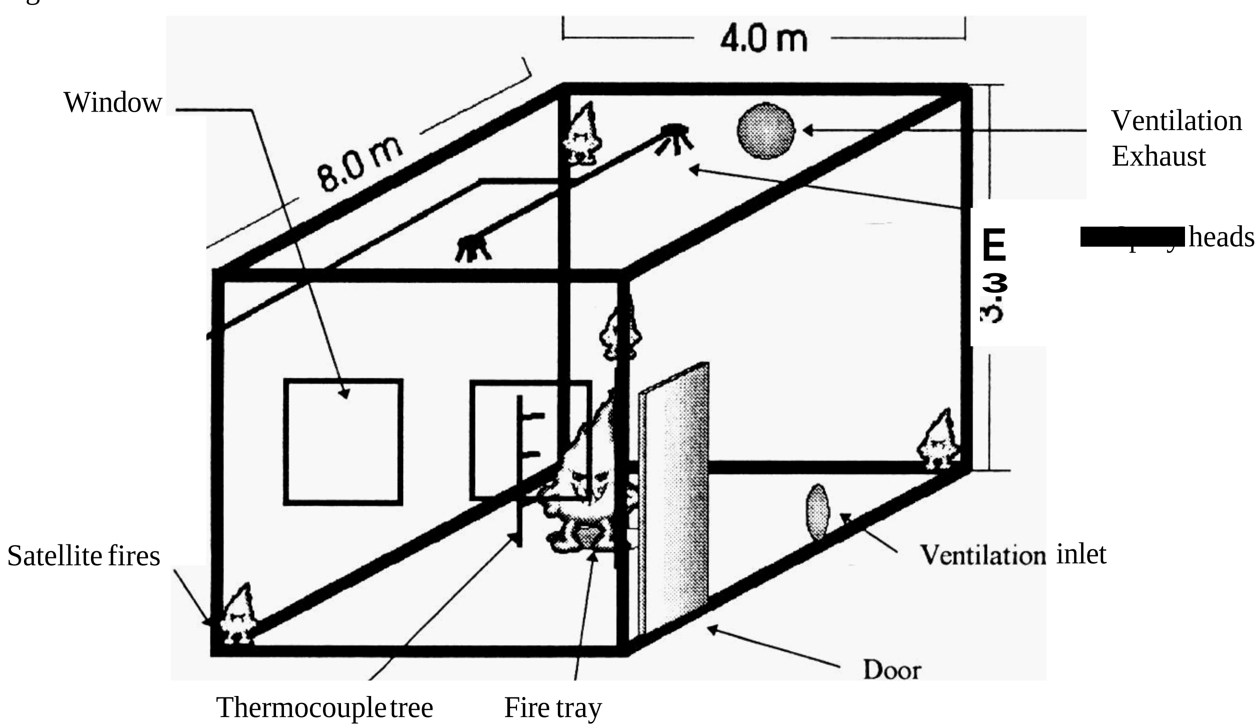
LOSS PREVENTION COUNCIL TRIALS

The aim of the LPC trials was to test the performance of two systems representative of low and high pressure types in the same conditions and against the same fuels as used in the LPC's work on comparison of gaseous halon alternatives[3]. This will enable comparisons to be made between the performance of watermists and gaseous agents (the subject of a forthcoming report). Full details of the latest work camed out are contained in the full LPC report[4].

TEST CHAMBER

Figure **1** shows the LPC test compartment which measures 8m x 4m x 3m giving an internal volume of $96m^3$. The 3m ceiling height is representative of a smaller warship machinery compartment although these particular trials were not aimed at replicating such a scenario. Ventilation was reduced to two 100mm dia drainage holes at the floor to give a relatively well sealed environment. Provision was made for 4 satellite fires in the corners of the room, two high up and two at floor level. These provided an indication of the distribution of the extinguishing system and its ability to tackle very small, awkwardly sited fires. Each was monitored by separate thermocouples.

Figure **1 - LPC** Test Chamber



FUELS & TRIALS PROCEDURE

The fuels used are shown in Table 1 and were the same as in the gaseous agent tests but with the addition of three fuels used specifically in Naval applications, Dieso F-76, Avtur F-34 and Dieso Soaked Fibres (DSF, a combination of polycarbonate pipe insulation and mineral fibre board soaked with fuel designed to represent a deep seated lagging fire). Sufficient fuel was used to allow a free bum time of about 10 minutes. The trials procedure involved igniting the fire followed by a pre bum period prior to mist application. Extinguishment was confirmed by temperature drop and visually through a viewing tube into the fire area. The data logger recorded inputs-from all instrumentation simultaneously throughout the tests. Fire position was varied during the programme from directly under a nozzle to an offset position. This tested the ability of each system to extinguish fires in a more difficult location. It should be noted that the fire sizes used at the LPC are relatively small compared to those used for most watermist trials and by their nature may be more difficult to extinguish than larger fires. This facility provides very comprehensive instrumentation for temperature, pressure and particularly gas analysis. However it should be noted that the steam dilution contribution to oxygen depletion, estimated to be around 2-3%, could not be accurately measured due to the drying process required by the analyser. Data collection is handled from all inputs simultaneously by a computer interfaced data logging system with sampling rates up to 2kHz.

WATERMIST NOZZLES & SYSTEMS

Two systems were trialled, one representing a typical low pressure type, the other a high pressure gas driven type. Both are commercially available and already fitted in a variety of applications including some commercial marine environments.

Table 1 - Fuel Data

NEL CLASS	*FUEL TYPE*	*TRIALS USED*	*DESCRIPTION & TYPICAL USES*	*FLASH POINT °C*	*AUTO-IGNITION TEMP °C*	*APPROX FIRE SIZE/OUTPUT*
A	SMALL WOOD CRIB	LPC ONLY	REDWOOD 24 IN No. (25 x 25mm STICKS)	-	-	0.20 Mw
	LARGE WOOD CRIB	LPC ONLY	REDWOOD 24 IN No. (50 x 50mm STICKS)	-	-	0.40 Mw
	PVC CABLE CRIB	LPC ONLY	6mm² PVC SHEATHED FLAT STRIPS IN CRIB	-	-	1.1 Mw
B	HEPTANE	LPC ONLY	COMMERCIAL n-HEPTANE	-	215	1.75 Mw
	DIESO F-76	LPC/FRS	PETROL DISTILLATE, DIESELS/GAS TURBINES	61	240	FRS 1.75 Mw
	AVTUR F-34	LPC/FRS	KEROSENE DERIVATIVE AIRCRAFT TURBINES	38	220	FRS 2.0 Mw
	OM-33	LPC/FRS	MINERAL HYD. OIL/NAVAL HYDRAULIC SYSTEMS.	160	n/a	FRS 1.5 Mw
HYBRID A/B	DSF	LPC/FRS	DIESO SOAKED INSULATION / MINERAL FIBRE BOARD	n/a	n/a	FRS 1.0 Mw

HIGH PRESSURE - GAS D R ''

The system tested is available in high pressure pumped, inert gas driven or compressed air driven versions. The inert gas type was tested in these trials and used nitrogen to propel water held in cylinders through a multi-orifice nozzle head at high pressure. The pressure decays during discharge from approximately 90 to 15 Bar (measured at the nozzle). The system produces a very fine high velocity spray, the characteristics of which are such that as the gas pressure reduces so the droplet size decreases giving a range of 120 to 20 microns. The gas is stored in one or more 50 litre bottles and by varying the number of nitrogen and/or water cylinders varying discharge times can be sustained.

RESULTS - *HP* GAS DRIVEN SYSTEM

Table 2 lists a selection of the test data and results for this system. Definition of the terms used in the results table under comments is listed below:

Rapid extinguishment	-	less than 30 seconds
Quick extinguishment	-	greater than 30 seconds but less than 90 seconds
Extinguishment	-	greater than 90 seconds but less than 360 seconds
Long extinguishment	-	greater than 360 seconds

Table 2 - LPC Results For Hp Gas Driven System

FIRE TYPE		*HP SYSTEM CONFIGURATION*			*EXTING.*	O_2 *min*	*SAT.*	*COMMENTS*
FUEL	*POSITION*	N_2 *CYL/NOM. PRESS.*	H_2O *CYL.*	*NOZZLE HEADS*	*TIME(S)*	*%*	*FIRES EXT.*	
Small Wood	under nozzle	3/175	3	2	301	15.64	1 of 4	Exting.
Large Wood	under nozzle	3/175	3	2	220	15.20	4 of 4	Exting.
PVC Cable	under nozzle	1/175	3	3	80	18.91	0 of 4	Quick exting.
300mm Heptane	under nozzle	1/175	3	3	9	19.23	0 of 4	Rapid exting.
445mm Heptane	offset from nozzle	2/175	3	3	455	14.62	4 of 4	Long exting.
445mm Dieso	under nozzle	1/175	3	3	16	18.85	1 of 4	Rapid exting.
445mm Dieso	offset from nozzle	1/175	3	3	(580)	16.24	3 of 4	Not exting. fuel out
445mm Dieso	offset from nozzle	2/175	3	3	533	15.36	4 of 4	Near to fuel out
445mm Avtur	offset from nozzle	11175	3	3	(1010)	14.19	4 of 4	Not exting. fuel out
445mm Avtur	offset from nozzle	21175	3	3	483	14.46	4 of 4	Long exiling.
DSF	under nozzle	11175	3	3	NIA	19.10	0 of 4	Not exiling.

The fastest extinguishment was achieved against heptane directly under a nozzle head, while a similar test conducted offset from the node head resulted in the extinguishing time increasing by an order of five. Good results were achieved against all Class A and B fuels when under a nozzle head, while times were much longer or not successful at all when offset. This system produces small high velocity droplets in the main phase of its operation, which are able to penetrate a fire plume directly beneath and cool the fuel surface, flame and locally deplete the oxygen. However for more distant fires the droplets appear to have lost most of their energy and are therefore camed away on the fire plume. Extinguishment then appears to be more dependant on 'global' oxygen depletion within the enclosure, predominantly by the fire, to the point of extinguishment. A contributory factor with the gas operated version of this system is the inerting effect of the nitrogen propellant. Tests without a fire indicated that the contribution to oxygen depletion was around 4% in these trials. A further indicator used at the LPC is a tray lip thermocouple. This showed that, if the lip temperature could be reduced to below the auto-ignition temperature of the fuel, then a successful extinguishment usually followed (provided the cooling could be maintained for long enough). The ability to extinguish satellite fires varied and depended on global oxygen depletion. Other aspects of this systems performance included an ability to scrub smoke from the atmosphere extremely efficiently and a low water consumption rate. Compartment cooling was quite good, the mean enclosure temperature dropping by around 50°C over the first 200 seconds of a typical fire. Overall, this system performed well against fires placed beneath the nozzle heads and less well when offset from the nozzle heads. This would indicate an ability to penetrate the fire and cool the fuel provided the nozzle head is correctly positioned. The long extinguishing times of the offset fires combined with reduced oxygen levels in these circumstances suggests a degree of reliance on 'global' oxygen depletion in these scenarios. When considering this point it is important to remember that relatively small fires were used. With larger fire sizes the fire would make a significant contribution to oxygen depletion and therefore assist the system.

LOW PRESSURE - PUMP DRIVEN

The nozzle selected to represent the LP type was the Wormald AMlO. This is shown in figure 2 and has a relatively large central orifice (3mm) with a spherical 'ball bearing' deflector mounted on two supporting arms. The mist droplet characteristics for this nozzle are shown in figure 3. For these tests the nozzles were supplied from a centrifugal pump at the manufacturer's recommended operating pressure of 12 bar. The number and spacing of nozzles was determined by the manufacturer's design information but initial distribution experiments showed the system to be ineffective if a 1.5 - 2m spacing was exceeded. After initial water distribution problems with the AM10 nozzles, it was decided to increase the number fitted from 6 to either 8 or 11, provision having been made for the extra 3 nozzles which could be introduced via isolating valves if required. This arrangement gave a maximum spacing between nozzles of 2m and a distance of 1m from the walls.

Figure 2 - Wormald AM10 Nozzle

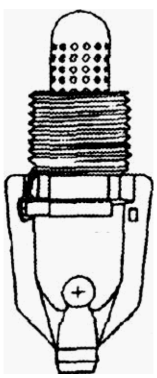


Figure 3 - AM10 Droplet Characteristics

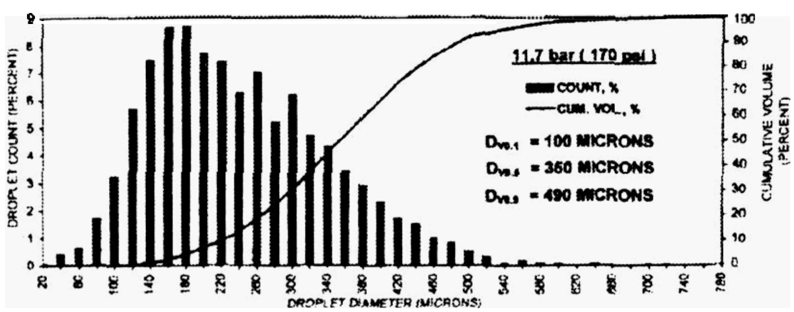


Table 3 lists test data for the low pressure pump operated system utilising this set up. It is clear that global oxygen depletion does not play such an important role in the extinguishing process with this system (although it may still happen local to the flame). The minimum value achieved was around 19% compared to 14% for the HP system. Extinguishing times are also generally longer. Interestingly the two lower satellite fires went out in every test, indicating the surface flooding nature of this nozzle layout. The higher satellites were not extinguished suggesting that the mist was not acting in a true 'total flooding' manner. The nozzle design results in relatively high water consumption, using 11 nozzles typically 400 litres for a 200 second discharge. A benefit of this is enclosure cooling which is excellent, a reduction in mean temperature of 70°C was recorded in the first 200 seconds of a typical discharge onto a Class B fuel. Smoke scrubbing was noted as being quite good, but not as good as for the HP system. Overall, provided the system is engineered correctly, it would seem capable of combating a range of fires efficiently being best suited to applications where rapid control of temperature is important. Also apparent is the simplicity of the nozzle, with a large orifice less likely to block or require as much maintenance as the HP types. On the downside, the system is likely to be more costly to install due to the number of nozzles and amount of pipework required (although through life costs may be cheaper than the HP types) and may use more water (depending upon the extinguishing time taken).

Table 3 - LPC Results For LP Pump Driven System

FIRE TYPE		*No. of*	*Operating*	*EXTING..*	*O_2 %*	*SATELLITE*	*COMMENTS*
FUEL	*POSITION*	*NOZZLES*	*Press (Bar)*	*TIME (S)*	*(Min).*	*FIRES EXT.*	
Small Wood	offset from nozzle	11	12	212	20.42	2 of 4	Exting.
Large Wood	offset from nozzle	11	12	309	19.24	2 of 4	Exting.
PVC Cable	offset from nozzle	11	12	110	20.04	2 of 4	Exting.
300mm Heptane	offset from nozzle	11	12	(461)	19.88	2 of 4	Not ext. fuel out.
445mm Heptane	offset from nozzle	11	12	263	19.29	2 of 4	Exting.
445mm Dieso	offset from nozzle	11	12	153	20.17	2 of 4	Exting.
445mm Avtur	offset from nozzle	11	12	235	19.96	2 of 4	Exting.
DSF	offset from nozzle	11	12	117	20.49	2 of 4	Exting.

NOTES: 1. NO FIRES EXTINGUISHED WITH 8 NOZZLE PATTERN
2. OXYGEN MEASUREMENTS DO NOT INCLUDE STEAM DILUTION CONTRIBUTION

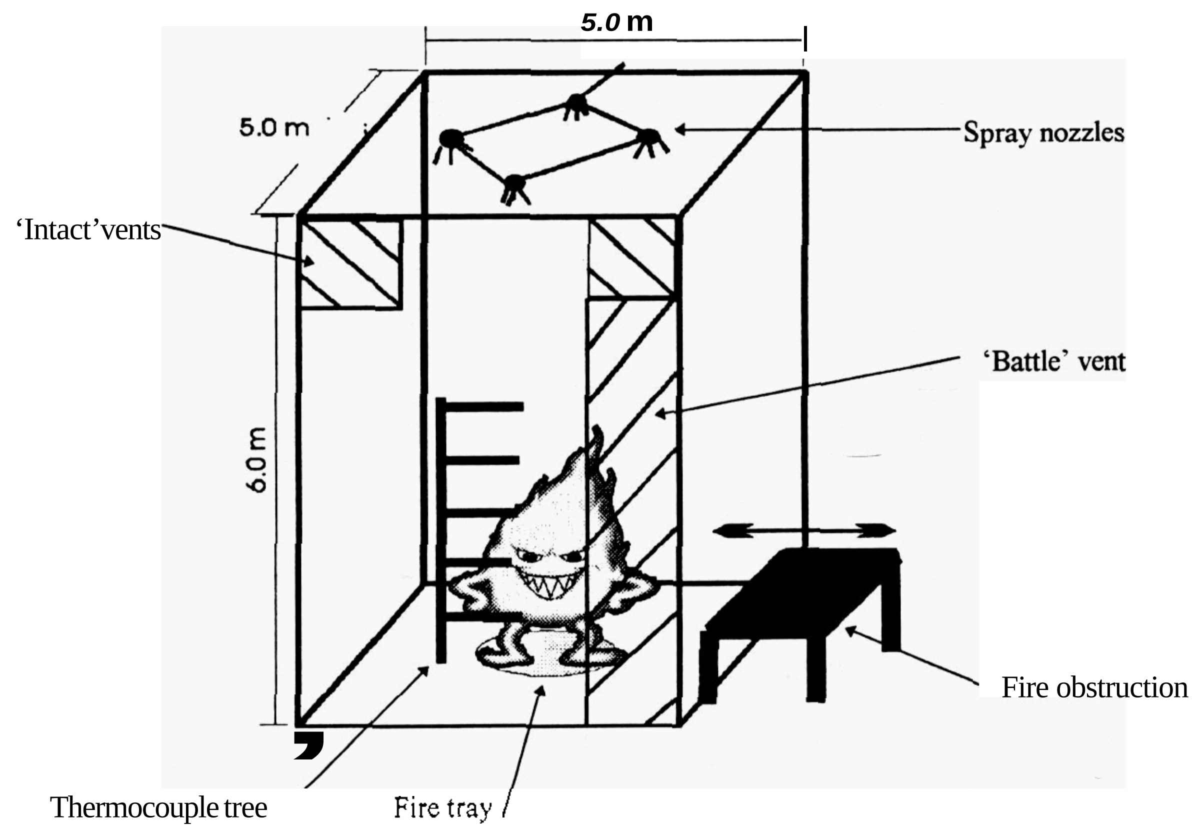
FIRE RESEARCH STATION TRIALS

The objective of the FRS trials was to investigate the effects of enclosure and obstruction on system performance. The trials were in two phases. The first tested a range of pump driven high and low pressure nozzles in the enclosed rig representing an 'intact' compartment. Two tests were made with each fuel, one unobstructed and one with a solid table obstruction placed over the fire at a height of 1.5m. The second phase used an inert gas propelled high pressure mist system with the same fuel and obstruction combinations but in two distinct ventilation scenarios. One, the 'intact' condition as used in the first phase, the other a 'battle damaged' condition representing, for example, a large shell penetration in the compartment. Full details of the latest trials are contained in separate FRS reports for the gas driven and pumped systems'. Due to programme constraints the 'battle damage' phase could not be completed for the pump driven nozzles during these trials. However during a previous phase of trials', all of these nozzles were tested in the same rig but in an unenclosed environment. The results of this work give a good indication of how they may perform in a 'battle damage' condition. Notwithstanding this the full 'battle damage' trials will be completed during the next phase of work.

TEST RIG

The rig arrangement, figure 4, gave an enclosed volume of $150m^3$ with three steel walls with the fourth able to be altered to give two states of free ventilation. The trials were planned to approximate the ventilation conditions of a typical frigate machinery compartment following forced vent fan shutdown but prior to manual close down of the external dampers and a 'battle damaged' condition with an increase in the ventilation area from approximately $1m^2$ to $3.75m^2$. The 6m ceiling height was representative of a large warship/auxiliary machinery compartment. Instrumentation was similar to that used at the LPC, utilising a thermocouple tree and oxygen analyser; again it is important to note that the steam dilution contribution to oxygen depletion could not be measured accurately but again was estimated to be around 2-3%.

Figure 4 - FRS Test Rig



FUELS & *TRIAL* PROCEDURE

For the FRS trials the choice of fuels was restricted to those most applicable to Naval applications; Dieso F-76, Avtur F-34, OM-33 and DSF. Sufficient fuel was used to allow a free bum time of about 10 minutes. Trials procedure involved igniting the fire followed by a pre bum period prior to mist application. Extinguishment was confirmed by temperature drop and visually through a viewing holes in the rig. A data logger recorded inputs from all instrumentation simultaneously throughout the trials.

WATERMIST NOZZLES & SYSTEMS

Table 4 shows the range of nozzle types used for all trials and details the nominal operating pressures and typical spray droplet diameters.

NOZZLE TYPE	*NOM. OPERATING PRESSURE (Bar)*	*MIST DROP SIZE (Microns)*	*COMMENTS*
HP GAS DRIVEN	**90 -15**	**120 - 20**	**Water in cylinders driven by compressed nitrogen**
NRL FLOODING SPRAYING SYSTEMS INC 7G-1	**70**		**US NRL modified version of 7G1**
NRL MK3 MODIFIED SPRAYING SYSTEMS	**70**		**US NRL modified version of 7G1 with larger orifices**
WORMALD AM10	**12**	**150400**	**Pump driven nozzle with spherical diffuser**
LECHLER 460-648	**7**	80-330	**Pump driven LP nozzle**

RESULTS AT FRS

Table 5 shows the results for the HP gas driven system. Tests without the obstruction and in the enclosed condition were generally very successful. Indeed the fastest time of any test was obtained against Avtur at 7 seconds and all Class B fuels tested were extinguished quickly. Performance with the table obstruction over the fire pan in the enclosed ventilation condition was still quite impressive, the extinguishing times were considerably longer, of the order of 8 times for Avtur and upto 15 times for the Dieso, but this was the only system to consistently extinguish Class B fuels under an obstruction. The difficult DSF was not extinguished, and in this case it appeared that insufficient mist had reached it to provide effective protection or control. In the 'battle damaged' scenario a full set of trials were conducted as before, but the results were very different. In the unobstructed trials, with the system using the same 1 nitrogen/3 water cylinder configuration the only success was against the OM-33 fuel. With the remaining fuels, the extra ventilation appeared to have a significant effect on the fire, not allowing the mist to really penetrate the plume successfully. The oxygen measurements at the plume do not appear to be very different to the enclosed condition. By adding an extra cylinder of nitrogen the ability of this system to cope with the extra ventilation was improved, although only the Avtur was extinguished in addition to the OM-33. It is likely that there were two beneficial effects: additional nitrogen assistance to the oxygen depletion and the discharge pressure being maintained over a longer period. All results were worse in the obstructed condition with no successful extinguishments being recorded and the DSF receiving little protection. It is clear from these results that a gas operated HP system of this type performs very well in relatively well enclosed conditions and has a good ability to penetrate obstructions from above More openly ventilated conditions have a significant effect on the performance of such a system, particularly against obstructed fires.

Table 5 - FRS Trial Results For HP Gas Driven System

FUEL	*RIG VENT. SCENARIO*	*FIRE SCENARIO*	*N_2 CYL.PRESS. (Bar)*	*H_2O CYL.*	*No. OF NOZZ's*	*O_2 MIN % @ PLUME*	*TIME TO EXT. (S)*	*COMMENT*
DIESO	Intact	Unobstructed	1/156	3	2	20.5	15	Rapid ext.
AVTUR	Intact	Unobstructed	1/175	3	2	20.8	7	Rapid ext.
OM-33	Intact	Unobstructed	1/158	3	2	20.3	28	Rapid ext.
DSF	Intact	Unobstructed	1/155	3	2	19.1	-	Min control
DIESO	Intact	Obstructed	1/170	3	2	17.0	225	Ext.
AVTUR	Intact	Obstructed	1/170	3	2	19.5	57	Quick ext.
OM-33	Intact	Obstructed	1/170	3	2	18.6	149	Ext.
DSF	Intact	Obstructed	1/170	3	2	17.8	-	Min control
DIESO	Battle	Unobstructed	1/151	3	2	16.7	-	No ext.
AVTUR	Battle	Unobstructed	1/175	3	2	15.6	-	No ext.
AVTUR	Battle	Unobstructed	2/153	3	2	19.8	41	Quick ext.
OM-33	Battle	Unobstructed	1/158	3	2	20.5	20	Rapid ext.
DSF	Battle	Unobstructed	2/155	3	2	19.9	-	Min control
DIESO	Battle	Obstructed	2/160	3	2	17.5	-	No ext.
AVTUR	Battle	Obstructed	2/157	3	2	16.8	-	No ext.
OM-33	Battle	Obstructed	2/165	3	2	18.5	-	No ext.
DSF	Battle	Obstructed	2/165	3	2	19.2	-	Min control

HP/LP PUMP DRIVEN SYSTEM - Table 6 gives the results for HP/LP nozzles systems.

NRL MODIFIED **SPRAYING** SYSTEMS ¾-7G-1 (NRL 'FLOODING' 70 Bar) extinguished all the class B fires without the obstruction, times varied from 130 to 480 seconds so were slower than some other systems. With the obstruction in position above the fire, both Dieso and OM-33 fires were put out, although these took a lengthy 469 and 487 seconds respectively and were getting near to fuel exhaustion. Again the DSF was not extinguished in either scenario although some protection was apparent when inspecting the remaining material after the fire.

NRL MODIFIED **SPRAYING** SYSTEMS 7G1 (NRL 'MK3' 70 Bar) the most improved nozzles from the previous open rig trials, these were proved to work very effectively in the enclosed rig. All fuels except the DSF were extinguished both unobstructed and covered. Extinction times varied from a quick 15 seconds for the unobstructed Avtur to a more lengthy 327 seconds for the obstructed OM-33. The unobstructed times were all good while the obstructed varied considerably. This was however the only nozzle other than the LP AM10 to put out all the liquid fuel fires in the obstructed condition. Damage limitation to the DSF was reasonable, but not as good as the AM10 nozzle.

The WORMALD AM10 (12 Bar) these nozzles gave an excellent set of results against the **Class** B fuels. **All** unobstructed fuels were extinguished in very fast times ranging from **13** to **36** seconds. Even obstructed the fires were all stopped in times ranging between **37** and **236** seconds. In both **cases** Dieso **was** the most persistent fuel for this nozzle to combat, this was more usually the Avtur fire for the other nozzles. This nozzle did not fully extinguish the DSF **fires** whether un-obstructed or obstructed, however inspection of the assemblies post test revealed the greatest degree. of control of any of the tested nozzles, more than 20% of the material remained intact.

LECHLER 460-648 (7 Bar) gave **good** results against un-obstructed liquid fires ranging in the most consistent (if not the fastest) extinguishing times of between 70 and 127 seconds. However, the **DSF** fire was not extinguished in either scenario although a degree. of damage control **was** afforded. The other fires proved more difficult in the obstructed test with only the **OM-33** being successfully extinguished in a relatively quick 62 **seconds.**

Table 6 - FRS Results For Pump Driven Systems (Intact Scenario only).

NOZZLE TYPE	*No. OF NOZZ's*	*FUEL*	*SCENARIO*	*PRESS.. (Bar)*	*O_2 MIN % @ PLUME*	*WATER VOL. USED (l)*	*TIME TO EXT.(S)*	*COMMENTS*
NRL FLOODING	4	DIESO	Unobstructed	70	17.4	116	199	Ext.
	4	AVTUR	Unobstructed	70	17.2	49	84	Quick ext.
	4	OM-33	Unobstructed	70	18.8	77	132	Ext.
	4	DSF	Unobstructed	70	18.2	-	-	No ext.
NRL FLOODING	4	DIESO	Obstructed	70	17.1	274	469	Long ext.
	4	AVTUR	Obstructed	70	16.0	-	-	Fuel out
	4	OM-33	Obstructed	70	17.3	284	487	Long ext.
	4	DSF	Obstructed	70	18.9	-	-	No ext.
NRL MK3	4	DIESO	Unobstructed	70	18.0	32	24	Rapid ext.
	4	AVTUR	Unobstructed	70	18.1	20	15	Rapid ext.
	4	OM-33	Unobstructed	70	18.7	43	32	Quick ext.
	4	DSF	Unobstructed	70	18.5	-	-	No ext.
NRL MK3	4	DIESO	Obstructed	70	17.3	213	160	Ext.
	4	AVTUR	Obstructed	70	17.7	89	67	Quick ext.
	4	OM-33	Obstructed	70	16.2	436	327	Ext.
	4	DSF	Obstructed	70	18.0	-	-	No exting.
LECHLER 460-648	9	DIESO	Unobstructed	7	17.5	142	127	Ext.
	9	AVTUR	Unobstructed	7	16.2	133	119	Ext.
	9	OM-33	Unobstructed	7	18.4	78	70	Quick ext.
	9	DSF	Unobstructed	7	18.0	-	-	No exting.
LECHLER 460-648	9	DIESO	Obstructed	7	16.0	-	-	No exting.
	9	AVTUR	Obstructed	7	15.9	-	-	No exting.
	9	OM-33	Obstructed	7	18.9	69	62	Quick ext.
	9	DSF	Obstructed	7	18.2	-	-	No exting.
WORMALD AM10	9	DIESO	Unobstructed	12	18.3	65	36	Quick ext.
	9	AVTUR	Unobstructed	12	18.5	31	17	Rapid ext.
	9	OM-33	Unobstructed	12	20.0	23	13	Rapid ext.
	9	DSF	Unobstructed	12	19.2	-	-	No ext.
WORMALD AM10	9	DIESO	Obstructed	12	16.8	425	236	Ext.
	9	AVTUR	Obstructed	12	17.5	69	38	Quick ext.
	9	OM-33	Obstructed	12	19.4	67	37	Quick ext.
	9	DSF	Obstructed	12	18.3	-	-	No exting.

NOTES: 1. OXYGEN MEASUREMENTS DO NOT INCLUDE STEAM DILUTION CONTRIBUTION

CONCLUSIONS

This series of trials utilised two different test compartments each tailored to research particular *aspects* of watermist performance including: comparison of HP and LP types in controlled conditions, performance against small and difficult fires, ability to tackle fires offset from the nozzles, environment tenability effects, effects of enclosure and oxygen depletion, effects of obstruction and performance against larger fires.

For the gas driven HP system the main extinguishing process ranges from either rapid fuel/flame cooling and local oxygen depletion when the nozzle is directly over the fire to a dependence on 'global' oxygen depletion by; fire consumption and nitrogen and *steam* dilution, and therefore *on* compartment enclosure when the fire is more remote.

For the pumped systems there appears to be much less dependence on 'global' oxygen depletion with performance relying more directly on cooling as a result of the increase water volumes provided by such nozzles. It is clear that careful engineering is required to ensure sufficient mist coverage as these systems do not work in a fully 'total flood' manner. Their ability to combat hidden or obstructed fires is not as good as the higher pressure system tested, but a good degree of control *can* be afforded to even persistent fires.

HIGH PRESSURE SYSTEMS

FOR
- better performance against obstructed fires
- gas driven types use relatively small quantities of water
- excellent ability to scrub smoke out of the atmosphere
- good atmospheric cooling ability
- relatively simple pipework and installation requirements

AGAINST
- performance may be affected by degree of enclosure
- use smaller orifice nozzles which may require finer system filtration requiring more frequent maintenance
- requires compressed gas to be available/stored on board or dedicated pumps

LOW PRESSURE SYSTEMS

FOR
- operating pressures closer to existing ship sea water mains pressures
- excellent atmospheric cooling ability
- good smoke scrubbing ability
- earlier trials indicate less dependence on degree of enclosure and ventilation
- simple nozzle with large orifice sizes - less fine filtration required and maintenance simplified

AGAINST
- less effective at extinguishing obstructed fires
- requires careful system engineering with large numbers of nozzles and an extensive pipework system
- *can* use relatively large amounts of water, may not be suitable in certain applications where free surface effects are important

Overall it is considered that the LP pumped system appears particularly suited to surface warship applications, especially if a system can be designed to operate effectively at nominal and across the range of standard fire main pressures. These systems seem most applicable for total compartment protection with a carefully engineered nozzle pattern tailored to the particular risk being protected. The high degree of cooling afforded and good smoke scrubbing abilities should allow early re-entry for fire fighters even if the fire is not fully extinguished. The HP systems would seem more suited to enclosed conditions or gas turbine/diesel modules. There also seems potential to examine this system for use in submarines where the compartments are enclosed, highly cluttered and where smoke scrubbing is important These systems also have the benefit of not introducing large quantities of water into the vessel.

FUTURE WORK/WAY AHEAD

These trials have greatly increased our understanding of the abilities of watermist as a possible alternative to halon for warships compartment protection. The capabilities of a range of high and low pressure systems have been explored in a variety of scenarios and against a range of fuels. The trials have also investigated the effect on performance of varying oxygen levels and the ability of different systems to combat hidden fires. Planning for the next phase of work is now well underway. It is intended to examine the abilities of a variety of the latest nozzle designs at ship mains pressures, the effect of additives, sea water and performance against spray fires. Construction of a calorimeter will also allow quantitative data to be taken which may be fed into future computer modelling work. Larger scale work will also be carried out to complete the 'battle damage' condition trials for the nozzles not yet tested and then proceed to examine different nozzle positions, fire positions and sizes in the current rig.

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