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REVISION OF RESOLUTION A.1050(27) TO ENSURE THE SAFETY OF PERSONNEL ENTERING ENCLOSED SPACES ON BOARD SHIPS

Oxygen depletion and gas emissions in enclosed spaces

Submitted by ICMA, IFSMA, IMarEST, INTERCARGO, INTERMANAGER, INTERTANKO, ITF and The Nautical Institute

SUMMARY

Executive summary:	Enclosed spaces on board all types of ships present serious risks to personnel performing their routine duties and many mariners have died over the years while entering and working in these spaces. This document proposes to raise awareness of the dangers in enclosed spaces from oxygen depletion due to rusting and the emission of dangerous gases from organic types of cargo due to biological degradation. The results of multiple experiments on a range of steel related spaces containing scrap metal cargo, along with chain lockers and ballast tanks. In addition, experiments on an array of organic types of cargo show the speed of depletion and the emission of toxic gases. The hazards from lack of Oxygen (O_2) and the build-up of gases such as Carbon Dioxide (CO_2) and Carbon Monoxide (CO) are well known, but their relationships are not always fully understood. Whilst testing for oxygen alone in steel related containments is the norm, it is not in itself appropriate when organic type of cargoes is involved when additional testing for carbon dioxide and carbon monoxide must be carried out.
Strategic direction if applicable:	6
Output:	6.23
Action to be taken:	Paragraph 13
Related documents:	CCC 9/INF.8 and CCC 9/INF.10

Introduction

1 The aim of the overall project was to raise awareness of the risks and hazards of entering enclosed spaces by highlighting how quickly the oxygen level can deplete to a dangerous level in an enclosed environment. The initial research project was to determine the rate at which oxygen depletes in steel related enclosed spaces using containers built specifically for this project. It is essential to emphasize that once the hatch covers or tank lids are closed, the oxygen contained within the space immediately begins being absorbed by the unprotected steel surfaces or by an organic type of cargo causing the emission of toxic gases.

2 Initial experiments on a range of steel related containments of scrap metal, chain lockers, and ballast tanks show how quickly the oxygen was absorbed through rusting in a simulated scrap metal cargo. The detailed results of these experiments are set out in document CCC 9/INF.9 on "Speed of Oxygen depletion in steel related spaces" and clearly show the speed of the oxygen depletion through rusting of exposed steel surfaces. The speed of oxygen depletion in a replicated chain locker was investigated using the sensor where a scale model tank and anchor chain that compared to a full-scale vessel was used. In addition, natural refreshment of the atmosphere in the model chain locker area was achieved with the seamless transfer of the experiment tank cover by another cover fitted with a suitably scaled opening. The natural refreshment experiments show that for the internal atmosphere to reach 19.5% oxygen level it would take several hours to achieve, thereby illustrating the dangers of immediate entry. Further experiments were carried out on a ballast tank model where the absorption of the oxygen due to rusting was based on bare steel dividers within the tank. Various bare steel areas were achieved using a mix of bare steel and plastic dividers. The results of the steel related experiments are shown in the table in annex 1.

3 A further series of experiments on a range of organic related cargoes show the speed of oxygen depletion in addition to the level of CO_2 and CO measured at the end of each experiment when the O_2 level had depleted. The detailed results of these experiments are set out in document CCC 9/INF.10 on "Experimental Study on Levels of Oxygen and Toxic Gases in Enclosed Spaces with Organic Material" along with the linkage of oxygen depletion and gas emissions from the cargo.

4 Experiments were carried on sawn timber, woodchip, wood pellets, logs and grain cargoes. The experiment results show the effects on the findings due to temperature, moisture content and permeability of the space. Linkage to a ship's cargo hold is through the permeability of the space.

5 Using the results from the various cargoes investigated, the next stage linked the depletion rate of oxygen to the emission of CO_2 that could prove that death from CO_2 poisoning would precede death from oxygen depletion. A formula was developed that linked the oxygen depletion and carbon dioxide emissions, enabling graphs to be produced that would show how to link the fatal level of CO_2 with the equivalent level of O_2 prevailing. Proof experiments were carried out to prove the theory on four batches of organic materials and showed remarkable consistency.

6 Experiments on wood pellet cargoes show the speed of oxygen depletion and the emission of carbon monoxide and the effect of the CO on the blood and the organs.

7 All organic experiments were then treated in a similar fashion using the formula with the results tabulated in an overall table. The findings are significant as they clearly visualize a number of important aspects. Within a few hours after closing the hatch cover, the enclosed cargo space will contain an extremely dangerous and fatal level of toxic gas whilst the oxygen level prevailing will be in the region of 14% to 16%.

8 Experiments on grain with an emphasis on the migration of gases within the hold illustrated that during the grain experiments the CO_2 builds up above the densely packed cargo thereby creating an earlier hazard. Proof experiments showed the extent of this hazard.

9 A table of the overall findings (annex 2) was created to illustrate the speed of oxygen depletion and to highlight the dangers associated with entry into unventilated spaces that contain materials capable of absorbing oxygen and generating toxic gases. Bearing in mind that an oxygen depleted atmosphere "looks normal" as there is no sensory indication to cause alarm regarding the dangers within the enclosed space, the results of the experiments should be seen as a significant step in raising awareness of the dangers within an enclosed space.

10 Considering that 4% CO_2 is the suggested fatal level and with the ceiling exposure limit (not to be exceeded) of 3% for a 10-minute period, it is suggested that there will be a declining health effect as the CO_2 increases above the 3% level. It is therefore reasonable to assume that extreme danger occurs between 3% and 4% CO_2. This suggests a "danger triangle" of the CO_2 levels and the time involved.

11 The creation of a more relevant table of the O_2 danger levels related to Organic Cargoes in light of the findings, along with an update of the existing CO_2 table of dangers is required to include as a minimum the dangers at exposure to 3% CO_2, in addition to an update of the existing CO table of dangers to include levels between the workplace exposure level and the suggested fatal level.

Proposal

12 It is proposed that the findings of this research be included in guidance for the entry into enclosed spaces.

Action requested of the Sub-Committee

13 The Sub-Committee is invited to consider the above proposal and the findings contained in document CCC 9/INF.9 on "Speed of Oxygen Depletion in Steel related spaces" and in document CCC 9/INF.10 on "Experimental Study on Levels of Oxygen and Toxic Gases in Enclosed Spaces with Organic Material"; therefore, taking into account the overall tables of results as shown in the tables included respectively in annex 1 and 2.

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ANNEX 1

STEEL RELATED EXPERIMENTS – TABLE OF FINDINGS

Type of Steel Related Experiment	Cargo Type	Free airspace in hold (µ)	Temp °C	Depletion time in hours to oxygen level of:								
				20%	**19.5%**	**18%**	**15%**	**12%**	**10%**	**6%**	**3%**	**1%**
Closed Experiment	Scrap Metal	90%	10°C	0.96	1.45	3.44	8.04	13.84	18.08	28.30	37.38	-
Closed Experiment	Scrap Metal	90%	23°C	0.19	0.30	0.46	0.80	1.21	1.56	2.41	12.67	-
Open Vented	Scrap Metal	90%	10°C	1.26	1.91	4.14	10.33	17.97	24.06	38.84	52.38	75.75
Open Vented	Scrap Metal	90%	23°C	0.59	0.84	1.55	3.12	4.64	5.68	8.03	10.13	12.00
Chain Locker	Anchor Chain	94%	10°C	3.08	4.53	9.13	18.46	30.37	38.48	58.17	77.25	95.83
Chain Locker	Anchor Chain	94%	23°C	1.44	2.05	3.83	8.03	13.25	17.25	27.17	36.50	46.08
Chain Locker Refreshment				**Refreshment time in hours to oxygen level of:**								
Type of Steel Related Experiment	**Locker Type**	**Free airspace in tank (µ)**	**Temp °C**	**3%**	**6%**	**9%**	**12%**	**15%**	**18%**	**19%**	**19.5%**	**20%**
Chain Locker Refreshment	Anchor Chain	94%	10°C	0.09	0.18	0.33	0.52	0.85	1.65	2.45	3.45	6.75
Chain Locker Refreshment	Anchor Chain	94%	23°C	0.15	0.25	0.37	0.53	0.83	1.59	2.04	2.49	3.42
Double Bottom Tank				**Oxygen Depletion time in hours to oxygen level of:**								
Type of Steel Related Experiment	**Bare Steel %**	**Free airspace in tank (µ)**	**Temp °C**	**20%**	**19.5%**	**19%**	**18%**	**17%**	**16%**	**15%**	**14%**	**13%**
Double Bottom Tank	48.75%	100%	12°C	7.75	15.50	26.33	47.08	88.58	115.67	157.25	198.75	216.13
Double Bottom Tank	48.75%	100%	23°C	0.90	1.65	3.20	9.13	18.43	30.51	45.94	65.72	86.37
Double Bottom Tank	42.56%	100%	23°C	0.91	2.34	4.49	11.74	24.79	42.53	67.14	92.75	126.74
Double Bottom Tank	36.56%	100%	23°C	0.96	2.77	5.66	14.30	28.54	50.00	72.58	99.45	138.20
Double Bottom Tank	30.47%	100%	23°C	1.21	3.91	7.38	17.03	30.31	51.55	77.32	99.92	135.81
Double Bottom Tank	24.37%	100%	23°C	1.46	4.02	7.86	20.47	41.97	71.03	104.02	137.92	169.86

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ANNEX 2

RESULTS OF EXPERIMENTS ON OXYGEN DEPLETION AND CO_2 LEVELS FOR ORGANIC CARGOES INCLUDING ESTIMATED TIME AND FATAL CONDITIONS

This table of results contains a summary of the experimental results for several Organic Cargo Types and include Temperature, Permeability of Cargo Space, Moisture Content of Cargo, Depletion Time in Hours, Conditions at End of Experiments, and Estimated Fatal Levels due to CO_2 and CO through calculations.

Table 14: Oxygen Depletion and CO_2 Levels for Organic Cargos including Estimated Time to Fatal Conditions.

Type of Organic Cargo	Experimental Conditions			Depletion Time in Hours to:				Conditions at End of Experiment				Estimated Time to reach Fatal CO_2 Level (4%)	
	Moisture Content %	Free air space in Hold μ	T°C	19.5% O_2	13% O_2	10% O_2	6% O_2	% O_2 Level	Duration	% CO_2	CO ppm	Est. Time to Fatal CO_2 Level	Est. % O_2 at Fatal CO_2 Level
Barley	15%	~48%	23°C	18.43	127.71	183.30	264.57	2.00	349.55	13.62	147.33	85	15.3
Wheat	18%	~48%	23°C	6.69	52.66	75.47	105.58	0.15	153.70	14.77	166.33	36	15.2
Sawn Timber	25%	~20%	11°C	3.14	61.47	117.34	198.39	6.00	198.39	7.17	26.67	63	13
Sawn Timber	25%	~20%	23°C	0.67	12.25	28.19	62.06	2.00	107.41	9.35	63	14	12.6
Wood Chip	34%	~35%	23°C	0.93	4.85	6.76	9.42	0.17	14.39	11.9	35	4.2	14
Beech	35%	~47%	23°C	1.20	6.77	9.56	13.87	1.00	22.60	16.7	18	4.3	15.8
Birch	35%	~47%	23°C	0.97	10.01	14.37	21.17	1.00	33.26	14.73	3	7.3	15
Hawthorn	37%	~47%	23°C	0.72	10.49	14.58	21.08	0.13	33.79	12.3	0.33	9.2	14
Hawthorn	17%	~47%	23°C	4.97	32.47	46.05	63.91	0.38	93.35	15.03	3.33	20.6	15.4
Larch	44%	~38%	12°C	3.24	21.68	32.32	48.83	0.28	91.05	14.43	535.00	17.5	15
Larch	44%	~38%	23°C	1.21	12.68	19.07	28.74	0.12	55.59	16.00	354.00	8	15.4
Oak	49%	~34%	12°C	1.93	11.66	16.27	22.44	0.08	37.16	13.40	0.00	9	14.8
Oak	49%	~34%	23°C	0.91	7.22	10.01	14.30	0.15	27.96	16.00	0.33	4.6	15.8
Oak	25%	~34%	23°C	1.36	11.54	16.43	23.32	0.05	41.49	16.53	270	6.8	16
Norway Spruce	66%	~47%	12°C	4.25	31.93	46.96	70.43	0.10	129.72	12.70	3.33	23	14.8
Norway Spruce	66%	~47%	23°C	1.18	16.22	24.41	36.83	0.07	69.73	16.23	5.00	9	15.7
Douglas Fir	56%	~44%	12°C	2.10	18.89	29.24	45.29	0.18	78.79	14.40	1.33	12	15
Douglas Fir	56%	~44%	23°C	0.95	11.87	17.57	25.68	0.15	43.36	16.43	1.00	6.5	15.7
Douglas Fir	25%	~44%	23°C	1.23	11.14	17.11	26.51	0.07	47.17	15.87	86.67	6.7	15.7
Scots Pine	68%	~43%	12°C	1.71	12.14	17.21	24.84	0.15	45.23	12.50	14.33	10	14.2
Scots Pine	68%	~43%	23°C	0.68	7.86	10.93	15.63	0.10	28.52	15.43	13.00	5.1	15.4
Scots Pine	30%	~43%	23°C	1.50	11.19	15.83	22.45	0.05	38.45	15.13	506	7.4	15.4
Sitka Spruce	57%	~40%	23°C	1.45	35.81	55.01	88.84	2.00	124.31	14.23	0.00	23	15.3
Oxygen Depletion and CO Levels for Wood Pellet Cargos including Estimated Time to Fatal Conditions.												1200 ppm CO Level	% O_2 at 1200 ppm
Wood Pellets	7%	~35%	23°C	15.92	157.71	-	-	13.00	157.71	0.2	1697	91.00	15.40