A Comparison Between the Laboratory and On-Site Testing on the New Ventilation System Proposed to be Used in the Ship Hull of an VLCC During the Repairing Process

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ABSTRACT

A new ventilation system was proposed to remove the smoke, heat and harmful gases generated during the repairing process of the ship hull of a very large crude carrier (VLCC). It basically transfers fresh air from the deck (top) to the bottom of the ship-hull via an air duct and then spread to the entire ship hull by an air distributor before being sucked out together with the smoke and dust via the suction at the deck. Laboratory experiments were performed using a scaled-down model of a ship-hull. The ventilation efficiency of the new system was determined as compared to the existing system. On-site testing using the prototype air distributor was also performed to measure the actual ventilation efficiency and to compare with the laboratory experiments. The main advantage of this new system is that it is easy to assemble and dismantle making it suitable when large scale, temporary ventilation is required.

1. INTRODUCTION

Laboratory experiments were performed using a scaled-down (1:12) model of a ship hull. The ventilation efficiency of the new system was determined as compared to the existing system. An on-site testing of the new system in an actual ship hull was performed to look into the effectiveness of the new system.

2. BRIEF DESCRIPTION OF THE TWO VENTILATION SYSTEMS

2.1 The new system basically supplies fresh air by fans installed on the deck of the VLCC and deliver this fresh air to the air distributors at the bottom of the ship hull via flexible plastic ducts. The air distributor will then distribute the fresh air throughout the entire hull, forming an upward-flowing, general displacement type of ventilation. Finally, the air suction fans, installed over various deck openings, will suck the air out of the hull and vent into the atmosphere.

2.2 The old system comprises only of air supply with attached flexible plastic ducting to deliver fresh air to the work zones. There were neither proper air distributing apparatus at the terminus of the duct nor any air suction fans mounted on the deck. The flow patterns in the ship hull are therefore random and the dust and smoke generated are circulated within the hull.

3. EXPERIMENTAL SETUP

3.1 The dimensions of the scaled-down ship hull were 4.17m(l) x 2.10m(w) x 2.50m(h), giving a volume of 22m^3. The experimental set up for this scaled-down model is shown in

Fig.(1) with two air distributors and three suctions at the top (ref.(1)). The old system was simulated using a smaller suction flow rate.

3.2 The dimensions of the ship hull (central tank) used for the on-site testing were 55.7m(l) x 20.8m(w) x 26.9m(h) giving a volume of $31165m^3$. The experimental setup for the new system had four sets of air supply fans on the deck connected to the four air distributors at the bottom of the hull via flexible ducts (see Fig.(2)). Six air suction fans were installed at the deck for exhaust and to balance the air flow rate. The setup for the old system was similar to that of the new system setup. The only difference was that the air distributors were removed.

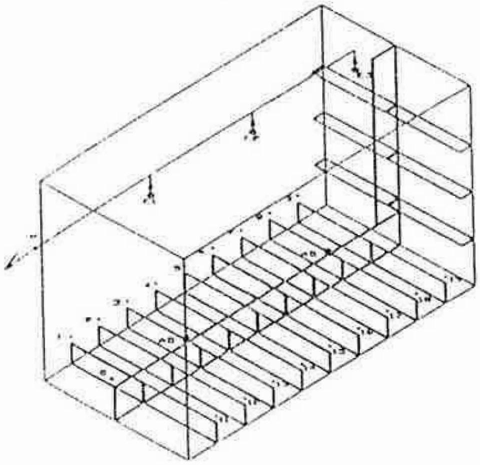

Figure 1: Experimental setup for scaled-down model

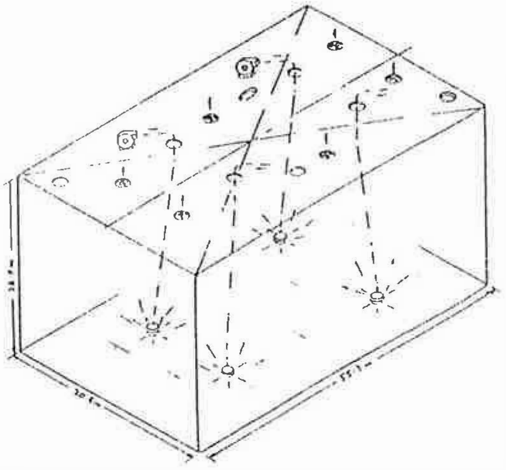

Figure 2: Experimental setup for on-site testing

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Air flow rate/Air-exchange rate

The total air supply and suction rates in the scaled-down experiment were $88m^3/h$ giving an air-exchange rate of 88/22 = 4 times/hr. As for the real-size on-site testing, the total flow rate was approximately $46,000m^3/h$ giving an air exchange rate of 46000/31165 = 1.5 times/hr.

4.2 Velocity at different distance from air distributor

4.2.1 The jets for both the scaled-down model and actual prototype air distributors were designed to be circular jets governed by Eq.(1). (see ref.(2)).

$$\frac{v_x}{v_o} = \frac{0.48}{\frac{ax}{d} + 0.145} \quad \text{.....................Equation (1)}$$

where d is the diameter of the nozzle
x is the distance from the nozzle
v_o is the velocity at the nozzle
v_x is the velocity at a distance x from the nozzle

From Table (1), it was observed that the turbulence coefficient, $a_{prototype}$, for the prototype was about twice that of the model. The higher the coefficient, a, implied that the distance reached by the jet was shorter because it had a wider angle of spread.

Table 1: Velocity at different distances from the air distributor

Prototype air distributor			Scaled-down air distributor (1/10)		
Distance from air-distributor (m)	Velocity (m/s)	Turbulence coefficient, a	Distance from air-distributor (m)	Velocity (m/s)	Turbulence coefficient, a
0	30.0	-	0.0	12.8	-
1	11.0	0.1047	0.5	2.1	0.0445
2	6.0	0.1015	1.0	1.0	0.0480
3	4.5	0.0917	1.5	0.7	0.0460
4	3.5	0.0893	0.0	20.0	-
5	2.6	0.0971	0.5	3.5	0.0416
6	2.5	0.0842	1.0	1.6	0.0468
7	1.8	0.1010	1.5	1.1	0.0458
8	1.5	0.1064	0.0	15.8	-
9	1.5	0.0946	0.5	2.5	0.0462
-	-	-	1.0	1.3	0.0455
-	-	-	1.5	0.9	0.0442
Average, a	-	0.0967	-	-	0.0454

4.3 Comparison of Using Concentration-Decay Method

4.3.1 *Scaled-down Laboratory Experiment* (refer to ref.(1) for more details)

Tracer-gas technique and concentration-decay method were used to determine the ventilation efficiency. The monitoring point for tracer gas (CO_2) concentration, in the common pipe at M (see Fig.(1)) where complete mixing was assumed, would measure the average room concentration of CO_2. CO_2 was emitted at a constant rate until steady state concentration was reached before it was shut off and the decay monitored. This was done to ensure uniform mixing of the CO_2 in the scaled-down testing chamber while not affecting the air flow pattern.

From Table (2), it was observed that the efficiency of the new system was double that of the old system (ref.(1)). It should be noted that the simulated old system still had flow rate while the actual old system had no suction at all. Therefore, the improvement over the existing old system should be reasonably more than double.

Table 2: Results on measurement of ventilation efficiency in scaled-down chamber

	Room Average Ventilation Efficiency, η_d
Flow rates at suction hoods (E1, E2, E3) m^3/h	2 air distributors at (44, 0, 44) m^3/h
3 suction hoods at (10, 10, 10) m^3/h	0.294
3 suction hoods at (29.3, 29.3, 29.3) m^3/h	0.575

4.3.2 On-site Testing (Real-size)

The dust monitor was set up at a location about 10m above the hull bottom, and near to the wall to simulate a typical working zone. Dust was released using smoke machines placed at the hull bottom and supplied through the flexible ducts till suitable amount of smoke was emitted before switching them off and the dust concentration was monitored. The decay of the dust concentration was the main concern and the units of measurement was number of particles-per-litre (p/l) for particles sizes >0.7μm and >1.0μm, averaged over time intervals of one (1) minute.

The normal atmospheric concentration of dust particle of size >0.7μm was 20,000 p/l and for size >1.0μm was 7,000 p/l. These figures were taken on an average of about 20 minutes when no work was being carried out.

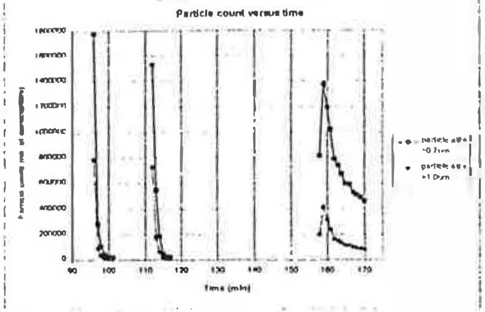

Figure 3: Dust concentration decay versus time for new (96th to 101st mins and 112th to 117th mins) and old (158th to 170th mins) systems

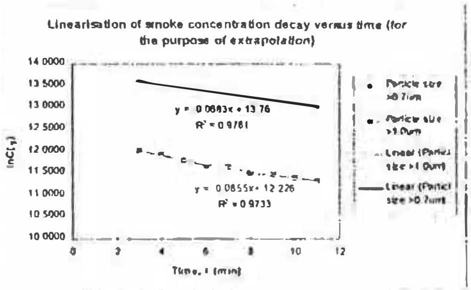

Figure 4: Linearisation of smoke concentration decay (of the old system for 162nd to 170th mins) by natural logarithmic method for extrapolation purposes.

Table 3: Three (3) minutes smoke concentration decay comparison

	Particle size >0.7μm			Particle size >1.0μm		
	Particle count (p/l)	C_2/C_1 (%)	No. of times above atm. conc. (20,000p/l)	Particle count (p/l)	C_2/C_1 (%)	No. of times above atm. conc. (7,000p/l)
$C_{1\,new}$	1,523,816	100.00	76.2	727,749	100.00	104.0
$C_{2\,new}$	40,545	2.66	2.03	13,065	1.80	1.87
$C_{1\,old}$	1,372,811	100.00	68.6	412,567	100.00	58.9
$C_{2\,old}$	790212	57.56	39.5	164,144	39.79	23.4

a. <u>Comparison of smoke concentration decay after a fixed time of three (3) minutes</u>

From Table (3), it was therefore evident that the new system could remove the smoke at an astonishing rapid rate comparatively with the simulated old system. A percentage decay of 2.66% (new system) against 57.56% (old system) for particle size >0.7μm and 1.8% (new system) against 39.79% (old system) for particle size >1.0μm were observed. It would thus be inferred that the new system could remove **about twenty (20) times as much of the dust concentration** as compared to the old system in a time span of 3 minutes.

Also, within this 3-minute span, the new system could bring the dust concentration level to only about two times (2.03 and 1.87 for particle sizes >0.7μm and >1.0μm respectively) that of the normal atmospheric concentration (see Table (3)). As for the old system, the dust concentration was still at a high 39.5 and 23.4 times, for dust particle sizes >0.7μm and >1.0μm respectively, that of the normal atmospheric concentration.

b. Comparison of time required for concentration to reach back to original atmospheric concentration

Table 4: Dust Concentration Decay for New System (112th to 117th minutes)

	Particle size >0.7μm		Particle size >1.0μm	
time (min)	concentration (particle/litre)	% of initial concentration	concentration (particle/litre)	% of initial concentration
112	1523816	100.00	727749	100.00
113	543421	35.66	174271	23.95
114	183868	12.07	64297	8.84
115	40545	2.66	13065	1.80
116	24847	1.63	7167	0.98
117	18984	1.25	5812	0.80

From Table (4), it took only 5 minutes for the new system to bring the concentration to fall below 20,000 p/l and approximately 4.2 minutes for the concentration to fall below 7,000 p/l for particle sizes >0.7μm and >1.0μm respectively.

For the old system, due to the long duration that was required for a full decay, a linear extrapolation of the natural logarithm of the concentration decay was employed using the last few readings obtained (Fig. (3) & (4)). This was extrapolated to predict the time required for the concentration to fall back to the normal atmospheric condition. It was predicted to require more than 56 minutes and more than 39 minutes, for particle sizes >0.7μm and >1.0μm respectively. Thus, by comparing the time duration for the dust concentration level to fall back to the normal atmospheric level, it could be seen that the time required was generally on the average of about **ten (10) times faster** using the new system as compared with the old system.

4.3.3 Some comments

There were some differences in the scaled-down experiment and the on-site testing:

a. The scaled-down experiment measured the global ventilation efficiency while the actual size test measured the local ventilation efficiency. Although local ventilation efficiency would be different for different location, a typical work zone was chosen. Also, global ventilation efficiency (as in the scaled-down experiment) would generally be lower than a well ventilated local area (on-site testing).

b. There were 4 air distributors, 4 supply and 6 suction fans for the on-site testing while only 2 air distributors and 3 suction hoods were used for the scaled-down experiment. Although there were this proportionate differences in the number of air distributors, supply and suction fans, the flow rates for the two hull sizes were in accordance with the dimensionless analysis, i.e.

$$C_l = 1/12 \qquad \text{(for length)}$$

$$C_l = C_l^{5/2} = 0.002 \quad \text{(for flow rate)}$$

e. The turbulence coefficient, a, for the scaled-down air distributor was half that of the real-size prototype air distributor. This would mean that, given everything else constant, the distance that the jet of the scaled-down air distributor could reach would be doubled. This would also mean that although fewer air distributors were used in the scaled-down experiment, the jet would still be able to reach the wall as in the on-site testing.

5 CONCLUSIONS

5.1 The construction of the scaled-down and real-size air distributor using dimensional analysis was generally useful. The only difficulty was the construction of the nozzle which would affect the turbulence coefficient, a, which in turn affect the distance reach by the jet.

5.2 Although two different methods, global and local ventilation efficiency, were used for the scaled-down and on-site testing respectively, both the results still demonstrated the effectiveness of the new system. This improvement was based on the respective simulated old system.

6 RECOMMENDATIONS

6.1 Further on-site tests and monitoring should be carried out with the new system.

6.2 Scaled-down experiments should be carried out to measure the local ventilation efficiency at the similar location as in the on-site testing for a better result comparison.

7 ACKNOWLEDGEMENT

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8 REFERENCES

(1) Xu WQ, H Sun, Sun QQ, etc. "Investigation of Air Flow Pattern of the Ventilation System in the Repair Process of VLCC", The 7th Int'l Conf. on Indoor Air Quality and Climate, Indoor Air '96, Nagoya, Japan. 21-26 July 1996.
(2) V.V. Baturin, "Fundamentals of Industrial Ventilation", Pergamon Press Ltd, Headington Hill Hall, Oxford U.K. (1972).