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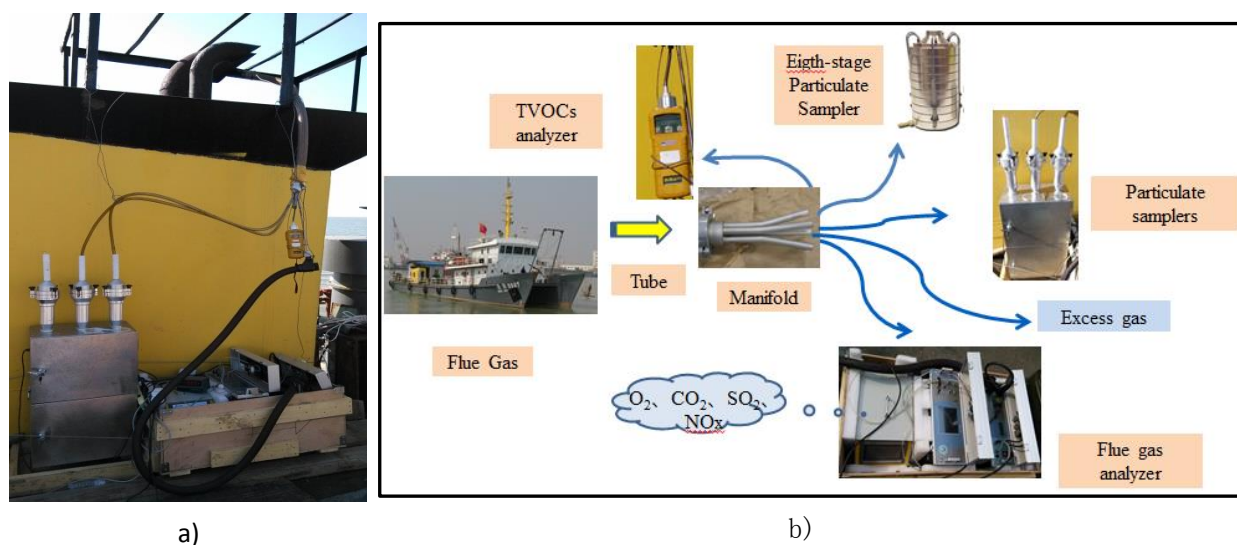
Emission factors for gaseous and particulate pollutants from offshore diesel engine vessels in China

Fan Zhang et al.

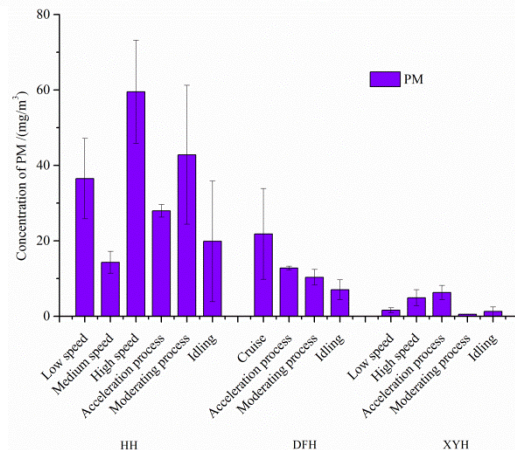
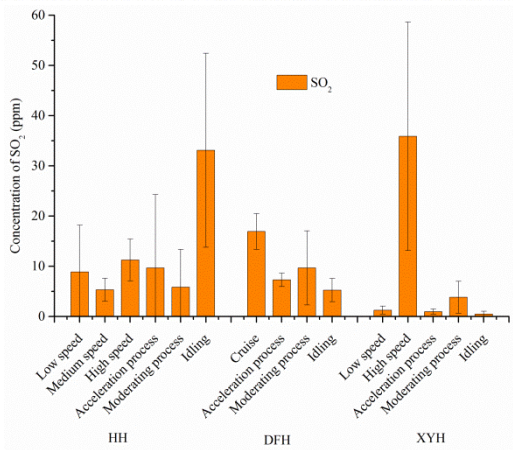
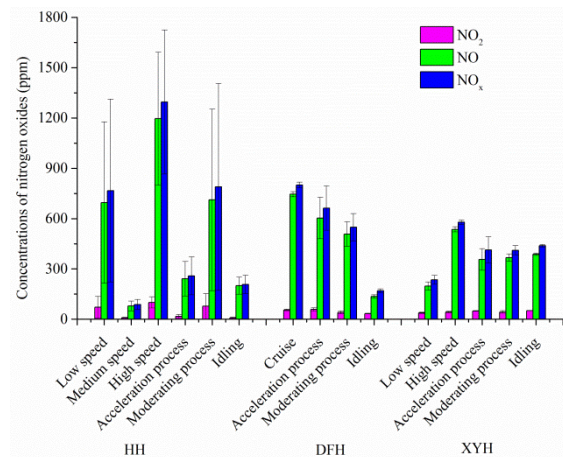
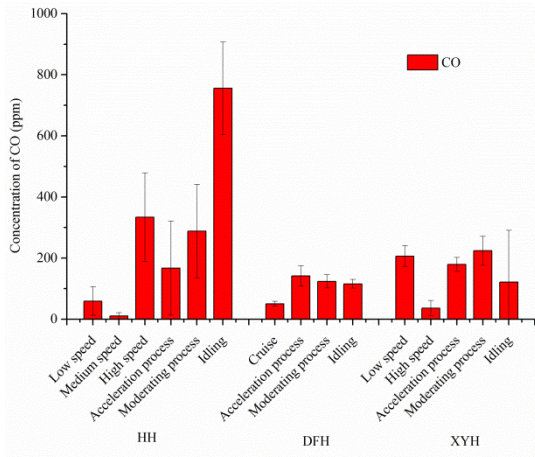
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1 Real-world Measurement System for vessels
2 Detailed composition and procedure of the on-board measurement system were
3 given as follows: The whole measurement system was placed on deck next to the
4 exhaust pipe of the vessel. A slender tube was placed into the vessel exhaust pipe to
5 lead out the flue gas. Then it was divided into five subsamples through a manifold
6 for different analyses and evacuation of the excess gas. The on-board test picture
7 (Figure S1, a)) and schematic diagram of the portable measurement system (Figure
8 S1, b)) are shown in Figure S1.



9 a) b)
10 Figure S1 Real-world measurement system for vessels: a) on-board test picture, b)
11 schematic diagram of the portable measurement system



1

2 Figure S2. Concentrations of main gaseous matter and PM in shipping emissions

1 Table S1 Types composition of offshore vessels in China

	Vessel type	Percentage %
Cargo ship	Tanker	18.03
	Liquefied gas carrier	1.11
	Chemical tanker	7.71
	Bulk carrier	14.98
	Container ship	5.61
	Ro-ro ship	3.21
	Other cargo ships	37.04
Other ship	push-tow ship	8.07
	Barge	1.07
	Non-transport Ship	3.17

2

3 Table S2 Distribution of vessels through gross tonnage in 2014 in offshore area of

4 Yangtze River Delta

Gross tonnage (t)	Percentage (%)
10000-49999	3.7
3000-9999	12.7
1000-2999	50.3
500-999	13.8
100-499	8.2
<99	7.0

5

6

1 Table S3 The Chinese market consumption of marine oil in 2011

Oil type	Application of ship type	Quantity demand (10 ⁴ ton)	
		Domestic trade oil	Bonded oil
Light fuel oil (density between 0.86 to 0.92) or equals DMA/DMB/DMC	Vessels with medium speed diesel engine of rmp above 300	400	125
180# fuel oil	Vessels with low speed diesel engine of rmp below 300	410	257
380# fuel oil		120	632
other heavy fuels (120#/250#/above 500# etc.)	120# applicable to medium or small fishing vessel; others applicable to new large vessels	70	85

2

1 Table S4 Detection parameters for the gaseous matter

Component	Method	Range	Resolution	Accuracy	Time (T ₉₀)	Conformity
O ₂	Electrochemical sensor	20.95%	0.01%	±5% rel.	45 s	ISO 12039, CTM-030
CO ₂	NDIR	5%	0.01%	±3% rel.	45 s	ISO 12039, OTM-13
CH ₄	NDIR	5%	0.01%	±3% rel.	45 s	
NO	NDIR	1000ppm	1ppm	±3% rel.	45 s	ISO 10849, Method 7E
NO ₂	NDIR	1000ppm	1ppm	±3% rel.	45 s	ISO 10849, Method 7E
SO ₂	NDIR	1000ppm	1ppm	±3% rel.	45 s	ISO 7935, Method 6C
N ₂ O	NDIR	2000ppm	1ppm	±3% rel.	45 s	ISO 21258
VOCs	PID	10000ppm	0.1ppm	±5% rel.	-	

2 NDIR, Non-dispersive Infra-red

3 PID, Photo Ionization Detector

1 Table S5. Fuel-based EFs for the gaseous pollutants for different operating modes

2 (g kg⁻¹ fuel)

Vessel ID	Operating mode	CO ₂	CO	NO	NO ₂	N ₂ O	NO _x	TVOC	SO ₂
HH	Low speed	3023±2236	6.08±4.77	76.4±52.8	12.0±11.2	0.81±0.47	89.2±64.3	50.7±83.7	
	Medium speed	3106±1753	15.3±15.6	121.6±43.9	20.2±6.01	0.77±1.69	142.6±51.6	20.6±19.4	
	High speed	3069±1342	12.7±5.50	48.6±16.1	6.23±2.08	1.82±0.34	56.6±18.6	29.9±23.6	
	Acceleration process	2940±1133	45.2±41.7	69.7±30.0	7.87±4.59	4.87±2.83	82.5±37.4	62.0±2.83	1.60
	Moderating process	3049±2005	26.0±13.8	68.7±52.3	11.5±11.2	2.65±1.54	82.8±65.0	30.8±24.6	
	Idling	2948±514	122±24.5	34.7±8.86	1.95±1.43	2.45±2.84	39.1±13.1	14.1±8.04	
DFH	Cruise	3160±141	1.88±0.30	29.9±0.59	3.37±0.30	0.01±0.01	33.3±0.90	1.24±0.07	
	Acceleration process	3157±197	5.91±1.38	27.0±5.55	4.06±0.62	0.37±0.38	31.5±6.55	-	0.92
	Moderating process	3157±180	5.81±1.02	25.5±3.67	3.15±0.61	0.45±0.39	29.1±4.68	-	
	Idling	3121±303	28.2±3.59	35.5±2.65	13.5±0.72	1.84±0.65	50.8±4.02	-	
XYH	Low speed	3102±409	32.2±5.26	32.9±4.04	9.67±0.84	0.65±0.42	43.3±5.31	9.15±0.00	
	High speed	3162±75.7	1.40±0.97	22.4±0.63	2.76±0.29	0.28±0.12	25.4±1.04	4.41±0.00	
	Acceleration process	3150±732	17.0±2.15	36.2±6.49	7.70±0.22	0.15±0.06	44.1±6.77	-	2.60
	Moderating process	3148±166	18.7±3.93	32.8±1.94	5.93±1.04	0.05±0.07	38.8±3.04	-	
	Idling	3162±72.4	9.97±3.80	34.0±0.56	6.86±0.19	0.05±0.02	40.9±0.76	-	

3 -, Unavailable data for TVOC

4

Table S6 Fuel-based EFs for PM and its chemical composition (PM, OC and EC are given as g kg⁻¹ fuel, others are given as mg kg⁻¹ fuel)

Vessel ID	HH						DFH				XYH				
	Operating mode	Low speed	Medium speed	High speed	Acceleration process	Moderating process	Idling	Cruise	Acceleration process	Moderating process	Idling	Low speed	High speed	Acceleration process	Moderating process
PM	1.29±0.52	4.62±3.09	1.00±0.49	1.86±0.29	0.97±0.30	2.08±1.09	0.65±0.36	0.43±0.02	0.39±0.08	1.33±0.49	0.19±0.08	0.15±0.07	0.47±0.14	0.04±0.00	0.09±0.08
OC	0.30±0.40	0.82±0.31	0.12±0.06	0.14±0.02	0.11±0.02	0.51±0.34	0.18±0.20	0.09±0.03	0.14±0.02	0.56±0.14	0.17±0.14	0.05±0.02	0.15±0.07	0.05±0.02	0.04±0.00
EC	0.47±0.20	0.72±0.60	0.58±0.25	0.10±0.34	0.15±0.00	1.70±1.69	0.22±0.16	0.34±0.12	0.19±0.03	0.42±0.03	0.04±0.02	0.09±0.03	0.22±0.12	0.02±0.02	0.03±0.00
NO ₃ ⁻	13.4±2.72	ND	3.40±1.99	ND	10.5±4.66	3.22±2.12	17.8±26.8	2.11±0.81	0.64±0.54	55.7±67.2	2.27±0.51	0.35±0.45	2.95±3.89	0.83±0.13	8.38±0.00
SO ₄ ²⁻	101±118	52.2±20.0	82.0±35.2	11.5±8.19	43.4±35.0	24.9±9.62	61.9±5.58	28.2±4.72	30.6±5.49	8.87±0.00	1.81±2.08	21.6±5.47	27.1±5.78	12.4±0.00	2.45±0.00
NH ₄ ⁺	16.0±8.01	86.9±16.5	7.76±1.45	29.2±0.03	20.9±9.41	15.9±6.07	5.27±4.52	1.48±1.07	3.11±0.78	2.51±1.62	2.85±0.20	3.71±0.92	3.01±1.72	4.03±1.75	4.97±0.00
Ca ²⁺	4.25±1.10	23.7±10.3	6.43±1.57	12.1±6.77	15.9±0.00	17.3±0.46	4.11±0.48	4.61±2.33	1.58±0.90	3.48±0.00	1.30±0.58	1.62±1.31	0.65±0.35	1.07±0.50	2.89±0.00
Cl ⁻	2.84±1.38	15.7±0.00	2.74±3.13	10.0±1.81	10.7±0.61	4.81±2.86	2.47±0.04	0.04±0.00	7.21±0.00	10.7±2.43	ND	0.04±0.00	ND	ND	ND
Na ⁺	2.51±2.55	3.95±3.15	2.69±2.23	0.94±2.93	3.55±0.40	3.37±0.17	1.12±1.06	0.79±0.33	7.00±0.00	7.50±9.48	1.32±0.58	1.94±0.34	1.78±0.25	2.28±1.04	3.30±0.00
V	0.23±0.07	0.76±0.04	ND	ND	0.51±0.03	ND	ND	0.03±0.00	ND	1.17±0.06	1.30±0.58	1.62±1.31	0.65±0.35	1.07±0.50	2.89±0.14
Cr	0.08±0.06	0.71±0.04	ND	0.19±0.13	0.13±0.01	0.08±0.00	0.24±0.33	0.01±0.02	ND	0.17±0.01	0.07±0.00	0.08±0.07	0.31±0.35	0.17±0.00	ND
Fe	0.11±0.11	0.92±0.56	0.02±0.02	0.04±0.00	0.04±0.00	0.12±0.06	0.20±0.28	0.02±0.01	0.01±0.00	0.13±0.01	0.03±0.01	0.03±0.00	0.02±0.02	0.05±0.03	ND
Ni	0.07±0.00	1.44±1.17	0.01±0.00	0.15±0.01	0.24±0.01	ND	0.03±0.02	0.03±0.02	ND	0.10±0.01	0.04±0.03	0.01±0.01	0.04±0.00	0.02±0.02	0.06±0.00
As	0.36±0.02	7.34±0.37	0.39±0.06	0.37±0.20	0.48±0.02	0.88±0.04	0.21±0.30	0.06±0.08	0.13±0.01	0.24±0.01	0.00±0.00	0.01±0.01	0.02±0.00	0.00±0.00	ND
Cd	0.22±0.01	3.91±0.20	0.14±0.01	1.35±0.82	3.46±0.17	0.14±0.17	0.31±0.19	0.05±0.00	0.03±0.01	3.18±0.16	0.00±0.00	0.03±0.00	0.04±0.04	0.32±0.28	0.54±0.03
Tb	1.20±0.17	0.47±0.02	0.48±0.07	6.78±1.18	2.32±0.12	3.51±3.61	0.36±0.04	0.48±0.02	0.80±0.04	1.54±0.08	0.12±0.10	0.30±0.18	0.05±0.36	0.76±0.61	1.30±0.07
Er	0.89±0.90	26.9±20.9	0.72±0.84	1.81±4.56	1.25±0.06	1.77±1.95	0.34±0.02	0.26±0.30	0.28±0.01	3.51±0.18	0.24±0.07	0.23±0.21	0.28±0.12	0.81±0.61	0.62±0.03
Yb	0.45±0.59	16.7±0.84	1.69±0.08	ND	0.04±0.00	2.73±1.91	ND	0.19±0.23	0.42±0.13	2.77±0.14	0.35±0.21	0.16±0.14	0.32±0.29	0.44±0.28	2.26±0.19
Lu	1.32±0.94	11.8±0.59	0.28±0.01	2.53±0.13	0.25±0.01	0.83±0.82	0.32±0.02	0.18±0.05	0.89±0.40	2.68±0.13	1.11±1.09	0.34±0.51	0.34±0.13	0.49±0.44	ND

ND, Not Detected;

1 Table S7 Actual navigation time of test vessels in different operating modes and their
 2 proportion factors to the whole voyage

Vessel ID	Operating mode	Average daily navigation time (h)	Proportion factor
HH	High speed	1	0.08
	Medium speed	8	0.67
	Low speed	0.6	0.05
	Idling	1.6	0.13
	Acceleration process	0.4	0.03
	Moderating process	0.4	0.03
DFH	Cruise	16	0.67
	Idling	2	0.08
	Acceleration process	4	0.17
	Moderating process	2	0.08
XYH	High speed	10	0.63
	Low speed	2.5	0.16
	Idling	1.25	0.08
	Acceleration process	1	0.06
	Moderating process	1.25	0.08

3