Pilot Green Transport Fund

Final Report On
Trial of Seawater Scrubber for Ferry
(The "Star" Ferry Company, Limited)

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(Trial Period: 1 December 2016 – 31 December 2017)

Executive Summary

1. Introduction

1.1 The Pilot Green Transport Fund (the Fund) is set up to encourage transport operators to try out green innovative transport technologies, contributing to better air quality and public health for Hong Kong. The "Star" Ferry Company, Limited (Star Ferry) was approved under the Fund for trial of a seawater scrubber comprising two identical seawater scrubber tanks and the associated operating system (herein called seawater scrubber). The seawater scrubber is connected to the diesel-electric propulsion (DEP) system of a ferry, named World Star, with a view to lowering the emissions of air pollutants (mainly sulphur dioxide, SO_2) of the ferry. Through the tendering procedure stipulated in the Subsidy Agreement, Star Ferry appointed Leung Wan Kee Shipyard to install the seawater scrubber system on World Star for trial.

1.2 Star Ferry is required to measure the emission concentrations at the inlet and at the outlet of the seawater scrubber to evaluate the performance of the seawater scrubber, once a month, during the trial. For this trial, there is no conventional counterpart available for comparison.

1.3 PolyU Technology and Consultancy Company Limited (PolyU) has been engaged by the Environmental Protection Department (EPD) as an independent third party assessor to monitor the trial and evaluate the performance of the green innovative technology under trial.

1.4 This report summarizes the performance of the seawater scrubber in the thirteen months of the trial.

2. Trial Product and Ferry

2.1 World Star has a diesel-electric propulsion (DEP) system, which includes two 465 bkW (425 ekW) Caterpillar diesel generators (No.1 and No.2 diesel generators), a 118 ekW Caterpillar diesel generator, two 500 kW electric motors and the associated control equipment. The two 465 bkW generators meet International Maritime Organization (IMO) Tier II and United States Environmental Protection Agency (USEPA) Tier 3 emission standards. A 465 bkW generator is to power the electric motors to propel the ferry and the 118 ekW generator is to provide electricity for on-board installation's use. Another 465 bkW generator is for stand-by purpose as required by

Marine Department for safety reason.

2.2 The seawater scrubber include two seawater scrubber tanks, seawater pumps and associated equipment. Each seawater scrubber tank serves one main diesel generator (425 kW diesel generator). The exhaust pipe of each main diesel generator is connected to the seawater scrubber tank inlet. The exhaust gas passes from the diesel engine to the seawater scrubber tank, is washed, and then leaves from the seawater scrubber tank outlet to the shipside exhaust. The smoke opacity and SO_2 concentrations in the engine exhaust were measured before and after the seawater scrubber tank to evaluate the efficiency of the seawater scrubber in reducing these emissions. The hydrocarbon (HC) concentrations in the engine exhaust before and after the seawater scrubber tank were also measured once in October 2017.

2.3 Key features of World Star, the seawater scrubber system and the measurement equipment and photos of them are in Appendix 1 and Appendix 2, respectively. World Star provides round trip service from Tsim Sha Tsui Pier to Disneyland Resort Pier twice a day, a round trip to Tsing Ma Bridge and a harbor cruise once per day. Daily operating hours for providing such service are about 11 hours.

3. Trial Information

3.1 The trial started in December 2016 and ended in December 2017. Star Ferry commissioned The University of Hong Kong (HKU) as Star Ferry's measurement team to conduct emission measurements of smoke and SO_2 once a month starting from December 2016 for 12 months. The measurement was not conducted in September 2017 due to maintenance of World Star but an additional measurement was conducted in December 2017 to make up for the twelve measurements. A measurement of HC concentration in the exhaust gas before and after the seawater scrubber was also conducted. In each measurement, three sets of data were recorded during each idling and cruising operation. The data were recorded when the readings reached steady-state.

3.2 Star Ferry was required to collect and provide trial information including World Star's operation data, seawater scrubber performance data and maintenance records. World Star's operation data include operating hours, fuel consumption and fuel cost. Seawater scrubber performance data include SO_2, smoke and HC emission data measured before and after the seawater scrubber. Maintenance records include cost and downtime associated with scheduled and unscheduled maintenance of the seawater scrubber. In addition to the cost information, reports on maintenance work and operational difficulties were collected to reflect any problems of the seawater scrubber.

4. Findings of Trial

4.1 Emission Measurements

4.1.1 The results of the measured concentrations of SO_2 and HC as well as smoke opacity and their reduction efficiencies are summarized in Table 1.

Table 1: Result summary of measured concentrations, smoke opacities and reduction efficiencies (December 2016 – December 2017)

		Measurement Results			
		Idling		**Cruising**	
		Before seawater scrubber	**After seawater scrubber**	**Before seawater scrubber**	**After seawater scrubber**
SO_2	Range	897 – 1,703 ppb	856 – 1,596 ppb	3,653 – 8,617 ppb	3,466 – 5,851 ppb
	Average	1,408 ppb	1,256 ppb	6,014 ppb	4,639 ppb
	Reduction	3.2% – 26.2%; Average : 10.8%		2.9% – 40.5%; Average : 22.9%	
Smoke	Range	1.6 – 7.8 HSU	1.0 – 7.7 HSU	0.7 – 4.9 HSU	0.6 – 3.8 HSU
	Average	4.7 HSU	4.4 HSU	1.8 HSU	1.6 HSU
	Reduction	-18.2% – 71.2%; Average : 8.0%		-10% – 35.7%; Average : 14.2%	
HC	Range	22.4 ppm	14.1 ppm	19.3 ppm	14.8 ppm
	Reduction	36.9%		23.3%	

4.1.2 The results show that the measured SO_2 and HC concentrations and smoke opacity in the exhaust gas are very low, both before and after the seawater scrubber, during idling and cruising operations. The average reduction efficiencies of the seawater scrubber for SO_2, smoke and HC were about 11%, 8% and 37% respectively during idling and about 23%, 14% and 23%, respectively during cruising.

4.1.3 A Feasibility Study of using similar seawater scrubber for ferry (i.e., Day Star) was conducted by Prof. Dennis Leung of Department of Mechanical Engineering at The University of Hong Kong and his team members in September 2008 (hereafter called the HKU Study 2008). Day Star had an old diesel engine similar to that of World Star before it was retrofitted with the DEP system.

4.1.4 Compared with the results reported in HKU Study 2008 for the old diesel engine, there were reductions of 83% in SO_2, 68% in smoke opacity and 80% in HC from the exhaust gas of the DEP engine, measured before the seawater scrubber. The significant reduction in SO_2 emissions of the DEP engine is due to the tightening of statutory diesel fuel sulphur content from 0.5% to 0.05%

while the significant reductions in smoke and HC emissions are due to improved engine technology adopted by DEP system. After passing through the seawater scrubber, there were additional reductions of 4% in SO_2, 5% in smoke opacity and 5% in HC, which are considered insignificant as compared with reductions associated with the tightening of fuel sulphur content and improved engine technology adopted by DEP system.

4.2 Operating Costs

4.2.1 Fuel consumption

The seawater scrubber incurred fuel consumption. There is a seawater pump which delivers seawater to the seawater scrubber. The fuel consumption of the seawater pump was about 1.1 litre/hr. The seawater scrubber, comprising of two seawater scrubber tanks, two seawater pumps, a piping system and seawater inside the system, weighed to about 2,000 kg. Based on the average fuel consumption of World Star of about 63.2 litre/hr during the trial period, the part related to the weight of seawater scrubber was about 0.35 litre/hr. Thus, the estimated total fuel consumption associated with seawater scrubber was about 1.45 litre/hr, including 1.1 litre/hr fuel consumption due to the operation of seawater pump and 0.35 litre/hr fuel consumption due to the weight of seawater scrubber. If this amount of consumption is deducted, the average fuel consumption of World Star would be about 61.7 litre/hr, i.e. the seawater scrubber increases the fuel consumption by about 2.4%. During the trial period, the total fuel consumption by World Star is 143,810 litre and the fuel consumption associated with the seawater scrubber (i.e. 2.4% of total fuel consumption by World Star) was 3,451 litres of diesel oil.

4.2.2 Maintenance Costs

There were one scheduled maintenance and three unscheduled maintenances for the seawater scrubber in the trial period (December 2016 to December 2017), incurring 7 hours downtime. The scheduled maintenance was concerned with cleaning and inspection of the seawater scrubber tanks and cleaning of the nozzles. It was conducted at time of the statutory overhaul of World Star in September 2017, thus no downtime was involved for this scheduled maintenance. However, it involved a maintenance cost of HK$14,570. Two unscheduled maintenances were related to crack found on the top of No.2 seawater scrubber tank, involving a total of 4 hours downtime. The other unscheduled maintenance was related to cleaning the seawater scrubber nozzles, involving 3 hours downtime. No maintenance cost was incurred for all the unscheduled maintenances as the seawater scrubber was still under warranty.

4.3 Performance and Reliability

4.3.1 During the trial period, there were one scheduled and three unscheduled maintenances on the seawater scrubber, leading to about one day downtime in total. Its utilization rate is therefore 99.7%.

4.3.2 The seawater scrubber nozzles need to be cleaned periodically in order to maintain its effectiveness in reducing the emissions. Star Ferry advised that the seawater scrubber would be cleaned annually.

4.3.3 Overall, Star Ferry agreed that the seawater scrubber could meet their operational requirements and its performance has not deteriorated with increasing time of operation. However, Star Ferry has reservation that the seawater scrubber helped saving operational cost. Moreover, due to the use of low sulphur fuel by law, the usefulness of the seawater scrubber which was originally designed to reduce SO_2 was not obvious.

5. Summary

5.1 Star Ferry found no problem in operating the seawater scrubber. The seawater scrubber was able to cope with its assigned duties with little maintenance. Its operation was smooth with utilization rate of 99.7%.

5.2 The seawater scrubber on World Star led to an increase in fuel consumption by about 3,451 litres of diesel (ie., 2.4% of total fuel consumption) with an equivalent carbon dioxide (CO_2e) emission of 9,031 kg generated.

5.3 The trial shows that since World Star uses low sulphur fuel and improved engine technology of DEP system, the SO_2, smoke and HC levels in the exhaust gas have been reduced by 83%, 68% and 80%, respectively as compared with the old diesel engine. After the seawater scrubber, the SO_2, smoke and HC levels were further reduced by 4% to 5%. Although the seawater scrubber could reduce SO_2, smoke and HC in the exhaust gas, the overall removal efficiency of the seawater scrubber is considered insignificant as compared with the effectiveness of the tightening of fuel sulphur content and improved engine technology adopted by DEP system. Having said that if the seawater scrubber is not installed, the ferry will save about 2.4% fuel consumption, whereby reducing the total emission of each type of pollutants. The environmental benefit of the seawater scrubber system adopted in this trial will be trivial compared to the adoption of the DEP system and the tightening of statutory fuel sulphur content.

Appendix 1: Key Features of the Trial Product and Ferry

1. World Star with Diesel Electric Propulsion (DEP) System

Retrofitted ferry

Name of vessel:	World Star
Type:	Class I Ferry Vessel
Port of Registry	Hong Kong
Length overall:	46.00 meters
Extreme breadth:	9.3 meter
Light Ship Displacement:	337,880 kg
Gross Tonnage:	364,000 kg
Net Tonnage:	109,000 kg
Passenger capacity:	408 people
Year of manufacture:	1989; retrofitted with DEP in 2016

Main Generator Set

No. of generator set:	2
Maker:	Caterpillar
Model:	C18 Marine Generator Set
Rating:	425 kW (531 KVA) @1800 rpm, 60 Hz
Engine:	6-cylinder in line diesel engine
Emission:	complied with IMO II / EPA Tier 3

Auxiliary Generator Set

No. of auxiliary generator set:	1
Maker:	Caterpillar
Model:	C7.1 Marine Generator Set
Rating:	118 kW (148 KVA) @1800 rpm, 60 Hz
Engine:	6-cylinder in line diesel engine
Emission:	complied with IMO II / EPA Tier 3
Propulsion Motor	
No. of motor:	2
Maker:	Dezhou Hengli
Model:	YVF2-4503-8-H
Rating:	500 kW, 440 V, 60 Hz

2. Seawater Scrubber System (two sets, each for one main generator)

Each seawater scrubber

Stainless steel scrubber tank:	2 (with spray nozzles and louvres)
Seawater pump:	2
Piping system:	1
Manufacturer:	Environmental Care Limited

3. Measurement equipment : Gas analzyers and smoke meter

Sulphur dioxide (SO_2)

Maker and model:	Model 100 UV Florescence SO_2 Analyzer, Teledyne Advanded Pollution Instrumentation
Measurement method:	UV Florescence SO_2 analysis
Measurement range:	0 to 20,000 ppb
Resolution:	0.1 ppb

Smoke intensity

Maker and model:	YDA309 Smokemeter 4, Hartridge
Measurement method:	light absorption method
Measurement range:	0 to 100%
Resolution:	0.1%

Hydrocarbons (HC)

Maker and model:	300 HFID, CAI Inc.
Measurement method:	Heated flame ionization detection
Measurement range:	0 – 30,000 ppm of carbon
Resolution:	1 ppm

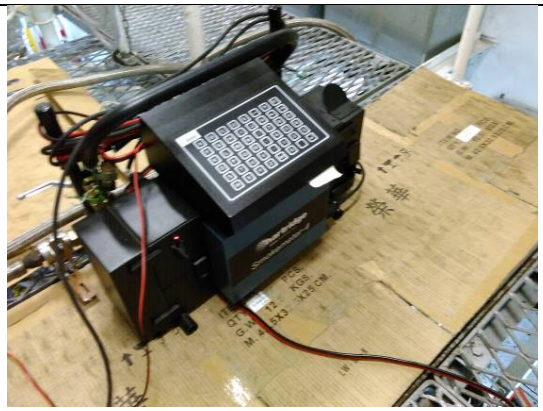
Appendix 2: Photos of World Star, seawater scrubbers and measurement equipment

Front view of World Star

Side view of World Star

Seawater Scrubbers with exhaust inlet

Seawater pumps for seawater scrubbers



Smoke meter

SO_2 gas analyzer

HC gas analyzer