Influence of Exhaust Gas Treatment System to the Possible Exhaust Gas Recovery

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***Abstract*— Environment Technology has been the major Breakthrough in 2010s, since the awareness of Global Warming increases rapidly. The Environment Technology is affecting whole Industry World with no exception to Marine World.**
Diesel Engine is undeniably the most frequent used machinery over the world and this trend is also the same with Maritime World. The usage of Diesel Engine will be resulting emission gas such as Sulphur and Nitrogen Oxide, which is highly dangerous for current Environment Condition. Both pollution types can be categorized as the acid material which very harmful to the environment and therefore MARPOL announces the requirement regarding the concentration of Sulphur and Nitrogen Oxide in order to maintain the quality of environment. It could be said that the appliance of this rule is supported by the public wholly, since these pollutions will not only slowly damage environment but also human body by causing acid rain and respiratory disorders. In order to fulfill the requirement of MARPOL The writer is trying to find the connection between EGTS and WHRS, and calculate the losses which are caused by application of EGTS. The calculation covers Chemical and Physical Calculation. From these connection and calculation, the writer gives analyzes how to use the Scrubber System with the possibility of WHRS including the suggestion how to improve the design of the EGTS in the future.

***Keyword*— Environtment Technology,Exhaust Gas Treatment System, Heat Loss, Scrubber Losses,Waste Heat Recovery System.**

I. INTRODUCTION

SHIPPING is one of the global industry and harmful emissions created from shipping vessels are affecting many regions worldwide. As a consequence Marine Industry is now challenged to adopt a new technology from the stricter international, national and local regulations to reduce emission from the ships.

Critical amongst these regulations are the measures to reduce the sulfur oxide (SOx) emissions inherent with the relatively high sulfur content of marine fuels. Ship designers, owners and operators have three general routes to achieve SOx regulatory compliance.

- Use low sulfur residual or distillate marine fuels in existing machinery,
- Install new machinery (or convert existing machinery where possible) designed to operate on an inherently low sulfur alternative fuel, such as liquefied natural gas (LNG), or
- Install an exhaust gas treatment system (EGTS) after treatment system.[1]

This statutory has been produced to reach the proper requirements applicable to SOx Exhaust Gas Treatment Systems (EGTS), or more known as scrubbers to provide an overview of available technologies. Marine air pollution regulations require the use of low sulfur fuel and the sulfate portion of the particulate matter (PM) emissions. The use of EGTS technology is called as an alternative of operating with low sulfur fuels. While EGTS systems have limited marine references at present, they are a proven existing technology with extensive experience and numerous applications to inert gas systems on tankers; they are considered a practical alternative for meeting SOx emission regulations.

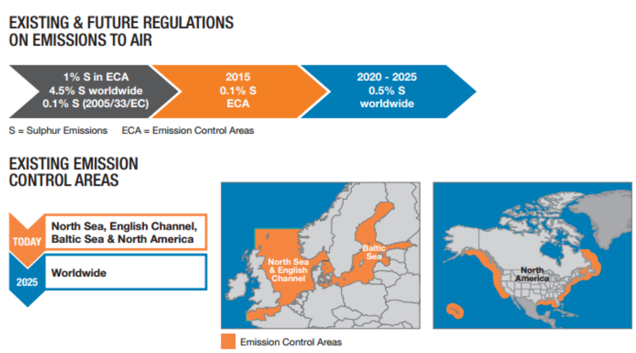

Figure 1 Existing & Future Regulation on Emissions to Air

The interest of reducing ship operating cost by adapting IMO EEDI rules calls for measures that ensure optimal utilization of the fuel used for main engines on board ships. Main engine exhaust gas energy is by far the most attractive among the waste heat sources of a ship because of the heat flow and temperature. It is possible to generate an electrical output of up to 11% of the main engine power by utilizing exhaust gas energy by comprising both steam and power turbines, and combined it with utilizing scavenge air energy for exhaust boiler feed-water heating.

In the standard high-efficiency engine version, the exhaust gas temperature is relatively low after the turbocharger, and just high enough for producing the necessary steam for the heating purposes of the ship by means of a standard exhaust gas fired boiler of the smoke tube design. However, the MAN B&W two-stroke ME main engine tuned for WHRS will increase the possibilities of producing electricity from the exhaust gas. The result will be an improvement in total

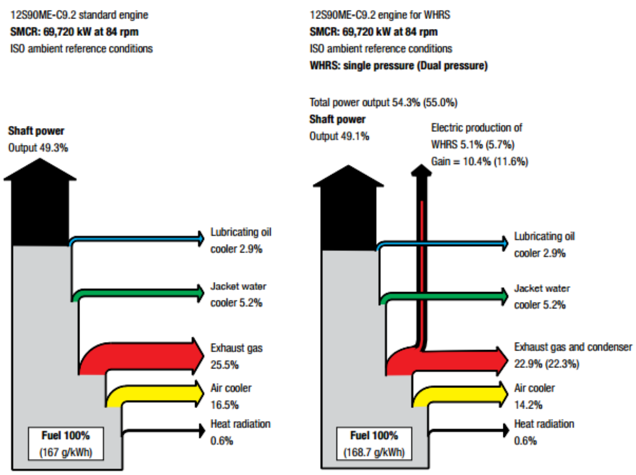

Figure 2 Existing & Future Regulation on Emissions to Air

efficiency but a slight reduction of the efficiency of the main engine will be seen. Fig.3 shows a comparison of engine heat balances, with and without WHRS. The figure shows that for the engine in combination with WHRS the total efficiency will increase to about 55%. The IMO EEDI formula allows for considering adding WHRS into the ship analyze EEDI effects and EEDI settings. As an even lower CO2 emission level can be achieved by installing a waste heat recovery system the EEDI, which is a measure for CO2 emissions, will also be lowered.[5]

II. STATEMENT OF PROBLEMS

A. *INFLUENCE OF EGTS ON WHRS*

The results of combustion process in diesel engine is Released in the form of Exhaust Gas. Inside of the Exhaust Gas consist of *Nitrogen Oxides(NOx), Sulfur Oxide (SOx), Hydrocarbon (HC), Carbon Monoxide(CO), and Particulates Matter (PM).* The impact of non-treated Exhaust gas can be shown by corrosion around exhaust gas tunnel which is caused by SOx . Not only SOx will impact to the Exhaust Gas System it is also impacting on environment. For example, Acid rain which is happened because of the reaction between SOx and H20. These cases will lead to the mandatory rules for the Exhaust Gas Treatment System.

The process through the Exhaust Gas to filter NOx and SOx substances inside of it , leads through Energy Losses in the process. Meanwhile, the process of NOx scrubbing is done on high temperature , which not convert to much heat to be released , on the other hand the scrubbing process of SOx is done by pouring Sea-Water on Open Loop System or Treat Water on Closed Loop System ,and this is done on Low temperature around 30-45 degree Celsius. This kind of treatment will lead to temperature drop, and the temperature drop is equal to energy release from the exhaust gas

B. *RESEARCH OBJECTIVES*

a) Calculate Losses through EGTS process. b) Compare the Exhaust Gas Losses from each designs to find the most efficiency to WHRS capability. c) Determine the best Exhaust Gas Treatment Systems in correlation to the Heat Recovery Potential. d) Analyze & Calculate the complete results of Comparison and Calculation to find the best solution and suggestion to improve the EGTS to reach WHRS efficiency.

C. *RESEARCH BENEFIT*

1) Understanding the technical data of scrubber due to SOx reduction.
2) Knowing the installation system of scrubber aboard ship to reduce SOx including scrubber’s structure and processes.
3) Determine the basic Chemical and Thermodynamic Losses from EGTS usage.
4) Understand how to improve the EGTS installation to improve the capability to meet WHRS requirement.

III. LITERATURE

A. *THERMAL RESISTANCE NETWORK*

Consider steady, one-dimensional heat flow through two plane walls in series which are exposed to convection on both sides. Under steady state condition:

rate of heat convection into the wall	=	rate of heat conduction through wall 1	=	rate of heat conduction through wall 2	=	rate of heat convection from the wall

From the following statement we can formulize that into:

$$Q^{\bullet} = h_1 A\left(T_{\infty,1} - T_1\right) = k_1 A \frac{T_1 - T_2}{L_1} = k_2 A \frac{T_2 - T_3}{L_2} = h_2 A\left(T_2 - T_{\infty,2}\right)$$

$$Q^{\bullet} = \frac{T_{\infty,1} - T_1}{1/h_1 A} = \frac{T_1 - T_2}{L/k_1 A} = \frac{T_2 - T_3}{L/k_2 A} = \frac{T_2 - T_{\infty,2}}{1/h_2 A}$$

$$Q^{\bullet} = \frac{T_{\infty,1} - T_1}{R_{conv,1}} = \frac{T_1 - T_2}{R_{wall,1}} = \frac{T_2 - T_3}{R_{wall,2}} = \frac{T_3 - T_{\infty,2}}{R_{conv,2}}$$

$$Q^{\bullet} = \frac{T_{\infty,1} - T_{\infty,2}}{R_{total}}$$

$$R_{total} = R_{conv,1} + R_{wall,1} + R_{wall,2} + R_{conv,2}$$

Note that A is constant area for a plane wall. Also note that the thermal resistances are in series and equivalent resistance is determined by simply adding thermal resistances

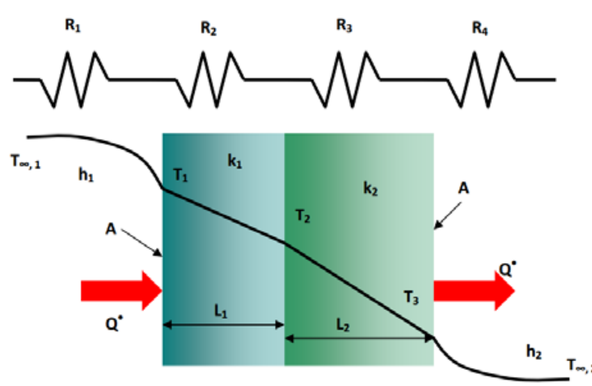

Figure 3 Thermal Resistance Network

Those calculation can be connected to Calculation of Multilayer Cylindrical Thermal Resistance Network so that we can make such an illustration of graphic as :

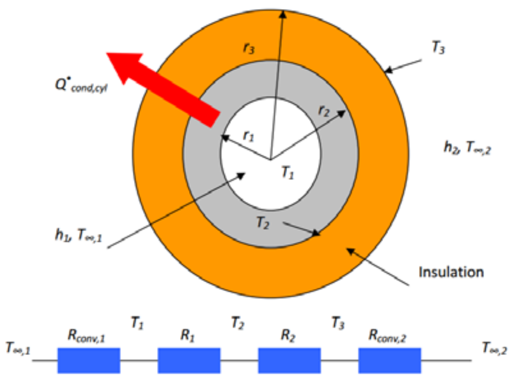

Figure 4 Multilayer Cylindrical Thermal Resistance

B. Calculation Regarding Radiation

Radiant heat loss occurs as a result of highly energized molecules transmitting heat by way of waves or particles. For significant heat loss to occur from radiation, the hotter surface must be well above ambient temperature -- much higher than what is observed in typical heat trace applications. Therefore, heat loss from radiation can be ignored.

In practical low-to-medium temperature applications, convection and radiation account for about 10 percent of the overall heat loss of a system. By adding 10 percent, the general formula for calculating the heat loss of a system via conduction, convection and radiation can be calculated.

C. Rockwool Insulation Thickness

Required insulation thicknesses If the three insulation systems are compared, taking into consideration similar heat losses, clear advantages are seen with regard to the insulation thicknesses with systems using Rockwool 850 pipe sections and Rockwool Duraflex load-bearing mats. These do not use spacers, in contrast to insulation systems made using wired mats. The table below shows the required insulation thicknesses taking into account the boundary conditions

Table 1 Rockwool Insulation Thickness

Nominal diameter Ø DN	NPS (inch)	Pipe diameter mm	Minimum insulation thickness: Pipe sections Rockwool 850	Minimum insulation thickness: Load bearing mats Rockwool Duraflex	Minimum insulation thickness: Wired mats ProRox WM 70
50	2	60	30	n.a.	n.a.
80	3	89	30	n.a.	n.a.
100	4	108	40	n.a.	n.a.
150	6	159	60	n.a.	n.a.
200	8	219	70	100	120
250	10	273	90	130	150
300	12	324	100	140 (2*70)	180 (2*90)
350	14	356	110	160 (2*80)	200 (2*100)

Multiple layer insulation   n.a. = not applicable

D. NOx Scrubber Working System

Nitrogen oxides (NOX) are reduced into nitrogen (N2) and water vapor (H2O) using Ammonia or urea at a suitable temperature on the surface of the catalyst. With minimum recommended temperature in the SCR compared to fuel Sulphur content. Those chemical products which is used NH3 and Oxygen to react NO into N2

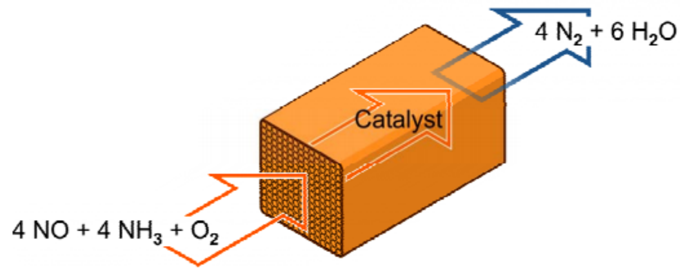

Figure 5 NOx with Catalyst Reduction

E. SOx Scrubber System

A scrubber is a device that installed in the exhaust system after the engine or boiler that treats the exhaust gas with a variety of substances including sea water, chemically treated fresh water or dry substances, so as to remove most of the SOx from the exhaust and reduce PM to some extent. After scrubbing, the cleaned exhaust is emitted into the atmosphere. All scrubber technologies create a waste stream containing the substance used for the cleaning process plus the SOx and PM removed from the exhaust. SOx (SO2 plus SO3) gases are water soluble. Once dissolved, these gases form strong acids that react with the natural alkalinity of the seawater, or the alkalinity derived from the added substances (normally sodium hydroxide), forming soluble sodium sulfate salt, which is a natural salt in the seas. In addition, the PM in the exhaust will become entrapped in the washwater, adding to the sludge generated by a scrubber. With dry scrubbers calcium hydroxide (Ca(OH)2), or hydrated lime as it is more commonly known, reacts with the SOx and solid calcium sulfate (CaSO4), or gypsum as it is more commonly known, is the product of the reaction. The waste stream and generated sludge has to be processed as per the IMO guidelines before discharge overboard, where allowed, or stored and discharged to shore as a waste substance.

<u>Engine Exhaust Gas Chemistry:</u>
S + O2 → SO2 ~ 95%
SO2 + ½O2 → SO3 ~ 5%

<u>SOx Reactions in a Scrubber:</u>
SO2 + H2O → H2SO3 *(Sulfurous Acid)*
SO3 + H2O → H2SO4 *(Sulfuric Acid)*

F. Open Loop Scrubber

An open loop-type scrubber uses sea water as the medium for cleaning or scrubbing the exhaust as shown in Figure 10. Sea water is normally supplied by a dedicated pump. CO2 dissolves in seawater forming carbonic acid, bicarbonate or carbonate ions depending on the pH. The positive companion ion can be calcium (Ca2+) or sodium (Na+) – here the sodium carbonate salt is used as an example. When the carbonate/bicarbonate ion reacts with an acid CO2 is released.

Na2CO3 + H2SO3 → Na2SO3 + H2O + CO2 *(Sodium Sulfite)*
Na2SO3 + ½O2 → Na2SO4 *(Sodium Sulfate)*

Na2CO3 + H2SO4 → Na2SO4 + H2O + CO2 *(Sodium Sulfate)*

Each EGC system manufacturer has their own techniques for how the scrubber mixes the exhaust gas and the water. As previously mentioned an open loop scrubber is only effective if the source water is alkaline. However, some river water is ‘hard’ water with significant alkalinity, in some cases higher than seawater, so open loop scrubbers can also work effectively in some port and river areas, but it is necessary to know the alkalinity of the water before this can be determined.

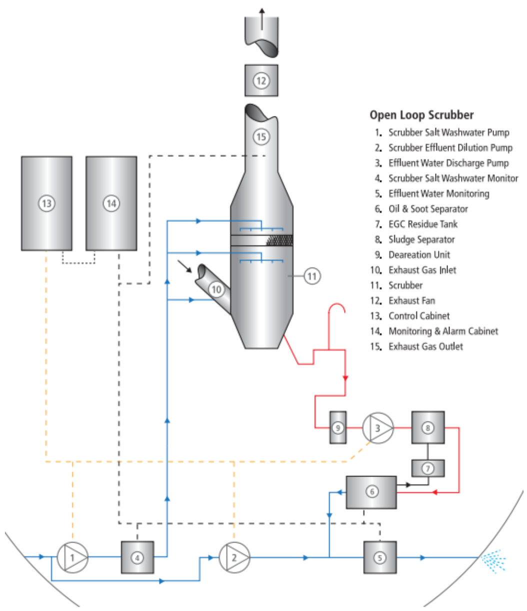

Figure 6 Open Loop Scrubber

G. *Closed Loop Scrubber*

In a closed loop-type scrubber, treated water is circulated through the scrubber to keep the scrubbing process independent of the chemistry of the waters the vessel is sailing in, plus there is little or no water discharged overboard from the scrubbing process, reducing the need for processing the washwater to make it suitable for discharge. Sodium hydroxide as a chemical additive is typically used in marine EGC systems to control the water alkalinity which can also be produced by electrolysis of seawater (see Figure 10).

The closed loop scrubber internals are similar to those of an open loop scrubber, and the chemical processes to remove the SOx missions are similar. The major difference between the two systems is that rather than going overboard, most of the circulating washwater is processed after it leaves the scrubber to make it suitable for recirculation as the scrubber washwater medium. The washwater can be fresh or salt water depending on the scrubber design. In this treatment process, the residues are removed from the water, and the water is dosed again with caustic soda to restore its alkalinity.

Manufacturers claim a closed loop scrubber requires about half or less of the washwater flow than an open loop scrubber to achieve the same scrubbing efficiency.

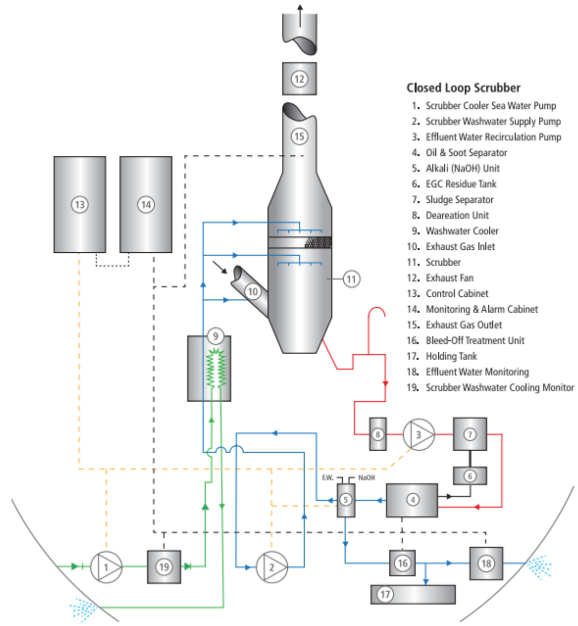

Figure 7 Closed Loop Scrubber

H. *Chemical Losses Calculation*

When chemical reactions take place they are often accompanied by *heat changes*. The system (the reactants which form products) may give out heat to the surroundings, causing them to warm up. In this case the reactants have *more* stored energy (greater total enthalpy) than the products. Such chemical reactions are said to be exothermic. The system may take heat from the surroundings, causing them to cool down. In this case the reactants have *less* stored energy (less total enthalpy) than the products. Such chemical reactions are said to be endothermic.

Exothermic reactions give out energy to the surroundings.
Endothermic reactions take energy from the surroundings.

Enthalpy, H In a sample of methane, CH_4, How much energy do its molecules contain? The first thing that needs to know is the amount of methane present. From the chemist’s side, so the answer is 1 mole (16 g). Energy is measured in joules, J, so by begin thinking where to start measuring from. There seems to be no starting point; can methane molecules ever have no energy contained within them? Indeed, it is *impossible* to know the total amount of energy stored in these molecules. Whatever its value, the total amount of energy in a given amount of a substance (sometimes called the Heat energy content) is known as the enthalpy, denoted H

I. *Sulphur Content inside of Fuel*

Theoretical emission of SO2 with exhaust gases

ST = maximum emission of SO2 = % S x 10,000 x 64 / 32 = % S x 20,000 = mg S / Kg Diesel oil

Concentration of maximum theoretical SO2 in gases, relative to % O2 measured:

A) Based on wet gases: SO2 (mg/Nm3) = ST / GHT

B) Based on dry gases: SO2 (mg/Nm3) = ST / GST

Concentration of maximum theoretical SO2 in gases, relative to Reference % O2:

A) Based on wet gases: SO2 (mg/Nm3) = (A) x (21 - %O2 Ref.) / (21 - % O2 measured)
B) Based on dry gases: SO2 (mg/Nm3) = (B) x (21 - %O2 Ref.) / (21 - %O2 measured)

Definisikan singkatan dan akronim ketika pertama kali ia digunakan dalam teks, walaupun telah didefinisikan dalam abstrak. Singkatan yang sudah populer di bidangnya tidak perlu disingkat, seperti IEEE, SI, ac, dan dc (elektronika). Singkatan yang mengandung tanda titik tidak membutuhkan spasi: tulis "C.N.R.S.," bukan "C. N. R. S.". Jangan menggunakan singkatan pada judul kecuali tidak dapat dihindari.

IV. PRINSIP-PRINSIP PUBLIKASI

A. Heat loss Through Pipe

The Steady-State Rate of Heat loss from the steam becomes:

$$Q = \frac{T\infty 1 - T\infty 2}{Rtotal} = \frac{255}{2.6876} = 94.88\ J/s$$

The total heat loss for a given length can be determined by multiplying the above quantity by the pipe length. The temperature drop across the pipe and the insulation are

$$\Delta Tinnerpipe = Q\ x\ Rinnerpipe = 21.58\ Celcius$$
$$\Delta Tinsulation = Q\ x\ Rinsulation = 220.296\ Celcius$$
$$\Delta Touterpipe = Q\ x\ Routerpipe = 13.1159\ Celcius$$

This is the result of the calculation of 1 length meter pipe , but following up this calculation there's a problem with the method which is used since there'll be a temperature drop from the inlet for each time and it's can scientifically be described as

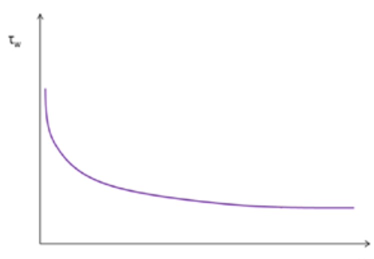

Figure 8 Temperature Drop on Pipe

Regarding this phenomena it's not wise to calculate the losses from each 1 meter as it is known the total length of the pipe is 5280mm, so the best approach is to calculate losses from each 10cm and then calculating the temperature losses from each 10cm and subtract it from the current temperature, and repeat this process until 5280 / 100 = 52,8 times which can be rounded up to 53 times. The calculation of this process will be done by program which I made to calculate data for each 10cm length.

It can be concluded from the work flow from the pipe through the whole process the total **Temperature losses = 29.41 and Work Losses = 255.23 J/s.** Taking Radiation into conclusion which is possible to be happen, 10 percent consideration is take to the Work Losses since the temperature losses in radiation will be very small and it can be unconsidered , so the new **Work Losses with$_{10\%}$ Radiation = 280.75 J/s**

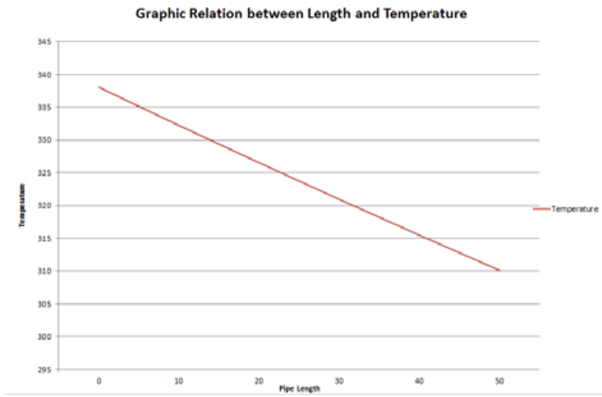

Figure 9 Graphic Relation between Length and Temperature

B. Heat Loss through Chemical Process in EGTS

To compare there are more than 1 type of catalyst which is used to remove the SOx and NOx concentration using scrubber system. The listed substances are usually used in the system.

Table 2 EGTS SOx Chemical Losses

Reaction	Enthalpy Formation		Enthalpy
Hydrated Lime :	Product	Reactants	(kJ/mol)
$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$	-1283	-1444.798	-161.798
Magnesium Hydroxide			
$Mg(OH)_2 + SO_2 \rightarrow MgSO_3 + H_2O$	-1221.49	-1570.74	-349.25
Caustic :			
$2NaOH(aq) + SO_2 \rightarrow Na_2SO_3 + H_2O$	-1130.61	-1376.18	-245.57
Sea Water :			
$SO_2 + H_2O + ½ O_2 \rightarrow SO_4^{2-} + 2H^+$	-582.66	-909.27	-313.95
$HCO_3^- + H^+ \rightarrow H_2O + CO_2$	-691.99	-679.33	
Calcium Carbonate			
$SO_2 + CaCO_3 = CaSO_3 + CO_2$	-1503.73	-1552.468	-48.738

Table 3 EGTS NOx Chemical Losses

Reaction	Enthalpy Formation		Enthalpy
Pure anhydrous ammonia	Product	Reactants	(kJ/mol)
$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$	357.06	-1714.98	-2072.04
Aqueous ammonia			
$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$	176.56	-1714.98	-1891.54
Nitrogen Dioxide Reactant			
$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$	-169.8	-3429.96	-3260.16
Nitrogen Dioxide Reactant (2)			
$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$	-118.08	-1714.98	-1596.9
Fastest Nitrogen Dioxide Reactant			
$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$	31.21	-857.49	-888.7

Table 4 SOx Chemical Losses Comparison

Table of Comparison					
	Ca(OH)2	Mg(OH) 2	2NaOH(aq)	Sea Water :	CaCO3
Enthalpy	-161.798	-349.25	-245.57	-313.95	-48.738
Losses (kJ/kg DO)	-15.047214	-32.48025	-22.83801	-29.19735	-4.532634
Comparison	3.319750503	7.1658665	5.0385736	6.441585621	1
Percentage	331.98%	716.59%	503.86%	644.16%	100.00%

Table 5 NOx Chemical Losses Comparison

Table of Comparison					
	Pure Amonia	Aqueous	Nitro 1	Nitro 2	Fast Nitro
Enthalpy	-2072.04	-1891.54	-3260.16	-1596.9	-888.7
Losses	-63.5213862	-57.987897	-4.3527848	-2.13209231	-28.430928
Combination	Pure + Nitro1	Pure+Nitro2	Aqu + Nitro1	Aqu + Nitro2	Fast Nitro
Losses (kJ/kg DO)	-67.874171	-65.653479	-62.340682	-60.1199897	-28.430928
Comparison	2.387335744	2.3092274	2.19270654	2.114598206	1
Percentage	238.73%	230.92%	219.27%	211.46%	100.00%

C. *Energy and Temperature Losses in Scrubber System*

To calculate the Losses which is happened in Scrubber, the approach of the calculation will be done by using the Energy and Temperature Balance from the system itself

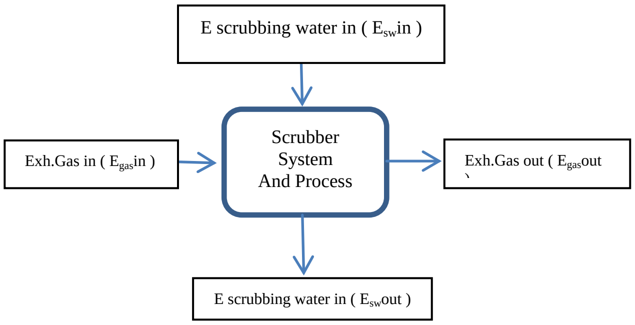

Figure 10 Scrubber Energy Balance

From the Following figure we can make a Formula which is :

$$E_{gas}in + E_{sw}in = E_{gas}out + E_{sw}out + E_{pipinglosses}$$

$$E = cp.\ \Delta T.\ M_{flowrates}$$

From the Following data that we have we can calculate as we already know the specific heat of exhaust gas and sea water which is 1,047 kJ/kg.K and 4.182 kJ/kg.K. And mass flowrate taking from the same 900kW Engine we know that the Mass flow rate is 1.64 for exhaust gas. The only problem to completing this calculation is the data of Mass flow rate Water which is unknown, and without any supported data we can't calculate this except we make a range of consideration. In order to calculate this, the kind of consideration which is used is the ratio of Mass flow rate water and Mass flow rate Gas which is know the Mass flow rate Water usually higher than the mass flow of the Exhaust Gas. That consideration is represented in a table as:

Table 6 Sea Water Mass Flow Rate Ratio

Table	Mass Flow Rate Water
Mass flow rate Water / Mass flow Rate Gas	
1	1.64
2	3.28
3	4.92
4	6.56
5	8.2
6	9.84

And from the Energy Formula we can calculate Energy input which is coming from the Exhaust Gas and Sea Water, and the data is separated into two since we have different temperature for both Open Loop and Closed Loop System

Table 7 Exhaust Gas Calculation

Mass Flow Rate Water	E water Open Loop	E in (gas + open loop)	E water Closed Loop	E in (gas + Closed loop)
1.64	2009.53	2937.56	1975.24	2903.27
3.28	4019.07	4947.10	3950.48	4878.51
4.92	6028.60	6956.63	5925.73	6853.75
6.56	8038.14	8966.16	7900.97	8829.00
8.20	10047.67	10975.70	9876.21	10804.24
9.84	12057.21	12985.23	11851.45	12779.48

T gas out Open Loop (in Celcius)	T gas out Closed Loop (in Celcius)	Mass flow rate Water / Mass flow Rate Gas
41.71	37.72	1.00
34.29	29.84	2.00
31.43	26.81	3.00
29.92	25.21	4.00
28.98	24.22	5.00
28.34	23.54	6.00

To determine the cp , it can be used the following approach formula :

$$(Tx - T1) / (T2 - Tx) = (Cp\ x - Cp\ 1) / (Cp\ 2 - Cp\ x)$$

and the following result of that approach is :

Table 7 Exhaust Gas Calculation

Mass flow rate Water / Mass flow Rate Gas	Open Loop	Closed Loop
1	0.978171	0.977772
2	0.977429	0.976984
3	0.977143	0.976681
4	0.976992	0.976521
5	0.976898	0.976422
6	0.976834	0.976354

Table 8 Losses Calculation Results

Losses Scrubber System		
Open Loop System	Closed Loop System	Mass flow rate Water / Mass flow Rate Gas
392.42	396.51	1.00
402.02	409.15	2.00
406.61	414.01	3.00
409.03	416.58	4.00
410.53	418.17	5.00
411.56	419.25	6.00

V. RESULTS AND ANALYSIS

A. *Results*

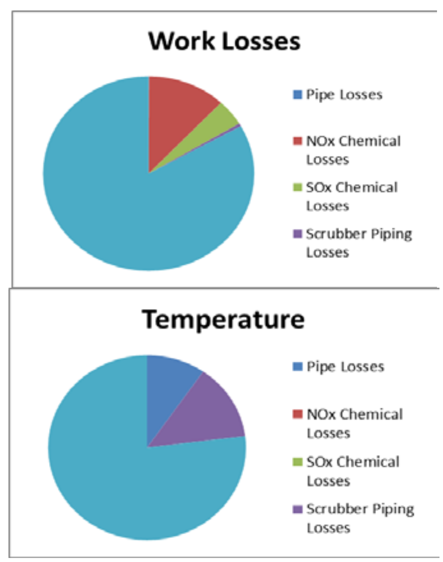

Figure 11 Losses Distribution

After completing all the calculation through the system we can make the summary of the losses to analyze the improvement of the system and how to override the losses to get the better chance of WHRS.

Table 9 Summary of Calculation

Summary of Calculation (Best Losses)		
	Temperature	Work Losses
Pipe Losses	29.41 Celcius	0.26 kJ/s
NOx Chemical Losses		28.43 kJ/s
SOx Chemical Losses		4.53 kJ/s
Scrubber Piping Losses	40.96 Celcius	2.33 kJ/s
Scrubber System Losses	233.34 Celcius	392.42 kJ/s
Total	303.71 Celcius	427.96 kJ/s

Summary of Calculation (Average Losses)		
	Temperature	Work Losses
Pipe Losses	29.41 Celcius	0.26 kJ/s
NOx Chemical Losses		56.88 kJ/s
SOx Chemical Losses		20.82 kJ/s
Scrubber Piping Losses	40.96 Celcius	2.33 kJ/s
Scrubber System Losses	235.56 Celcius	394.46 kJ/s
Total	305.93 Celcius	474.75 kJ/s

Summary of Calculation (Maximus Losses)		
	Temperature	Work Losses
Pipe Losses	29.41 Celcius	0.26 kJ/s
NOx Chemical Losses		63.52 kJ/s
SOx Chemical Losses		32.48 kJ/s
Scrubber Piping Losses	40.96 Celcius	2.33 kJ/s
Scrubber System Losses	237.78 Celcius	396.51 kJ/s
Total	308.16 Celcius	495.10 kJ/s

Summary of Calculation (without EGTS)		
	Temperature	Work Losses
Pipe Losses	29.41 Celcius	0.26 kJ/s
Scrubber Piping Losses	40.96 Celcius	2.33 kJ/s
Total	70.37 Celcius	2.58 kJ/s

B. *Imrpovement on EGTS to maximize WHRS potential*

1) Better heat-resist material inside the pipe

Table 17 Carbon Steel Usage as Replacement

Differences :		
	Temperatire	Work Losses Comparison
Best Losses	9.252717 Celcius	1.000000115
Average Losses	9.252717 Celcius	1.195701456
Maximum Losses	9.252717 Celcius	1.240546739
without EGTS	9.252717 Celcius	1.000019001

We can save up to 9 degree Celsius and save 0.19 less Work Losses from the steel only by changing the material, this mean the better the material is , more temperature that and Losses that we can save.

2) Shorter Pipe Length to Achieve less heat loss

$$Q = \frac{T\infty1 - T\infty2}{Rtotal} \ and \ Rcond = \frac{\ln(\frac{rn+1}{rn})}{2\pi k.L}$$

With less pipe usage, it's undeniable we can save a number of Heat and Temperature Losses by reducing significant number of pipe length , since pipe length is directly impact the Conduction Losses which will summed up to Heat Loss.

3) Putting Consideration on Chemical Products

Comparing Maximum Losses and Minimum loses we are able to get 16,54 higher loses compared to the other substances can be seen on Table 4 and 5

4) Using the Acid-Free Material on Scrubber Piping System

Taking the current regulation which has no requirement on temperature inlet of the scrubber system , if we have the acid-free material installed on the system than we can compromise the existence of acid rain on piping system since there will be no disadvantage if we have acid free material. The number of saved energy is come from the lower limitation of temperature before it entered. Currently , we only have 128,59 degree Celsius (308,59 – 180 = 128,59^{o}C) because the 180^{o}C regulation , and by this application we can deduct on the very low level , rough assumption 70 ^{o}C then we will have 238,59 ^{o}C to be used on the WHRS.. This can be a huge impact on WHRS since if this possible, then we can take a conclusion if EGTS is very supporting the WHRS process , by eliminating Acid Rain Factor.

C. *EGTS Doesn't Affect WHRS*

Based on some voyage experiences it is concluded that Acid Rain happen on 160-180^{o}C of Exhaust Gas with Sulphur Content inside of it. By removing the calculation of SOx Chemical Reaction, SOx Piping and System Losses it can be determined the number of losses post NOx Scrubber , and there are only minor losses before the system entered scrubbing process and WHRS is applied before it as well.

D. *The Best Installation of EGTS*

Post ME , Pre-EGTS -> Highly Not Recommended

The main problem of this Systems is the requirement of NOx EGTS which is needed 300^{o}Celcius to operate the scrubbing system. So we can only use 38 ^{o}Celcius to WHRS.

Post ME and EGTS-> Not Recommended

The main disadvantage of putting WHRS systems after EGTS systems is the SOx Scrubber process which is resulting the highest number of losses in Heat since there are 250^{o}Celsius or more difference in Temperature between the coolant and the Exhaust Gas, so we can only use 40 ^{o}Celcius

Post NOx EGTS , Pre-SOx EGTS - > Recommended

Compared to the other type of EGTS, this installment can used up to 94,71 degree celcius without any appliance of acid free material in scrubbing system, so this is the highly recommended system to be used

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REFERENCES

[1] ABS:Exhaust Gas Scrubber Systems Status and Guidance(2013).
[2] Wartsila:Exhaust Gas Cleaning(2015).
[3] MAN B&W:Exhaust Gas Scrubber Systems Status and Guidance,Emission and EEDI(2015).
[4] M. Bahrami: ENSC 388 (F09) Steady Conduction Heat Transfer.
[5] Calculating Heat Loss.www.process-heating.com/articles/87988-calculating-heat-loss
[6] Rockwool: Process Manual - Technical guidelines for the insulation of industrial installations.
[7] Wartsila: NOx Reducer Presentation(June 2011).
[8] ABS: ABS EXHAUST GAS SCRUBBER SYSTEMS ADVISORY.
[9] Rockwool: Comfort Instulation – Basic Theory.www.rockwool-searox.com/application+-c12-+constructions/comfort+insulation/basic+theory
[10] Engineering Tool Box: Overall Heat Transfer Coefficient. www.engineeringtoolbox.com/overall-heat-transfer-coefficients-d_284.html
[11] Avogadro(Co.UK):Enthalpy.www.avogadro.co.uk/h_and_s/enthalpy
[12] Cho, S.M. "Properly Apply Selective Catalytic Reduction for NOx Removal", Chem. Eng. Prog.(Jan. 1994).
[13] Wärtsilä. *Wärtsilä Scrubber Product Guide.* Revision D. (June 2014).