ANALYSIS OF AIR POLLUTION LEVEL DUE TO EXHAUST GAS EMISSIONS FROM KRI IN THE KOARMADA B

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ABSTRACT

Exhaust gas from ships is a source of air pollution, which has a very detrimental impact on the environment and living things. Global warming, storms, drought, floods, melting of the north and south polar ice which causes sea levels to rise then causing tidal flooding, forest fires, and disruption of human health, are the impacts and dangers of air pollution. Exhaust gas emissions from KRI operations contribute to air pollution. Based on these conditions, the authors feel it is important to conduct research to determine the level of exhaust emissions so that they can be used as a reference for the Indonesian Navy's policy in supporting the Indonesian government's efforts to prevent air pollution. The research was conducted using a combination of quantitative and qualitative methods. The numerical analysis approach by calculating the value of KRI exhaust emissions is carried out then the results of the calculations are analyzed using a descriptive qualitative analysis approach. From the research results, it was found that 87.5% of KRI had exceeded the allowable exhaust gas emission limit, while only 12.5% were still within the tolerance limit.

Keywords: *Exhaust Emission, Air Pollution*

1. INTRODUCTION

Exhaust gas from ships is one of source air pollution, which has a very detrimental impact. The impact of pollution is a very serious threat to the environment and living things. Exhaust gas emissions from ship activities, including the operational activities of KRI, contribute to the increasing concentration of pollutants, including carbon dioxide, nitrogen oxides, sulphur dioxide, petroleum hydrocarbons, and particulars, if not controlled, will accelerate the increase. The concentration of gases in the atmosphere causing global warming.

Global warming occurs when the earth's global average temperature or surface increases. The cause of this is the result of air pollutants and greenhouse gases gathering in the atmosphere and then absorbing sunlight and solar radiation that bounces off the earth's surface. This radiation should normally go to outer space, but due to pollutants, radiation and sunlight are trapped in the atmosphere. This phenomenon is known as the greenhouse effect as the cause of global warming. The gases that cause the greenhouse effect include Carbon Dioxide (CO2), Nitro Oxide (NOx), Sulphur Oxide (SOx), Methane (CH4), Chlorofluorocarbon (CFC), Hydrofluorocarbon (HFC).

Based on BMKG data, in 2019, there was an increase in the average temperature in Indonesia of 0.58 ° Celsius. This makes 2019 the second hottest year since the range of temperature increases in 1981-2010 after 2016 (BMKG, 2021). The World Meteorological Organization (WMO) revealed that there was an increase in the global average temperature of 1.1 ° Celsius. The UN's climate change and global warming report show 2019 to be the hottest year in the past five years. The UN report states that the average global temperature in 2015-2019 is in the warmest path (CNN, 2021). This increase resulted in many natural disasters due to rising earth temperatures during 2019, such as storms, drought, floods, melting of the north and south polar ice, which caused sea levels to rise, causing tidal flooding and forest fires. Another impact on the maritime security sector, according to Basil

Germond (2019), states that climate change due to global warming affects the level of maritime security of a country's territory.

One of the sources of air pollution is the maritime sector, in which there are marine operational activities. Indonesia's maritime transportation network is significantly more advanced than air transportation, with nearly 90% of international trade being conducted by sea (Dijk et al., 2015). According to Dong (2015), the sea transportation mode is the prima donna in the business world because of its high carrying capacity and more competitive costs than other modes of transportation. Based on business economic factors, it makes Indonesian waters crowded and congested. Moreover, of the 9 (nine) choke points that are owned by the world, 4 (four) of them are in Indonesia as an international shipping route, namely the Malacca Strait, Makassar Strait, Sunda Strait, and Lombok Strait. This condition requires the Indonesian Navy to deploy the KRI fleet as its SSAT to secure the territorial waters of the Indonesian State in the face of the hectic Indonesian maritime transportation route.

Based on the conditions mentioned above, one of the sources of air pollutants in the maritime world, which in this case is the operational activities of ships, so the Indonesian Navy is also a potential source of air pollutants. Thus, this is what underlies the importance of this research being carried out to determine the level of KRI exhaust emissions to be used as a reference for the Indonesian Navy's policy in supporting the Indonesian government's efforts to prevent air pollution.

This paper has many works of literature to support the research, for example, paper with the title: The Analysis of Greenhouse Gas Emissions Mitigation: A System Thinking Approach (Case Study: East Java) (Jatmiko, Suryani, & Octabriyantiningtyas, 2019), Fuel Consumption and Vehicle Emission Models for Evaluating Environmental Impacts of the ETC System (Weng, 2015), System Dynamics Modeling For Urban Energy Consumption And CO2 Emissions: A Case Study Of Beijing China (Feng, Chen, & Zhang, 2013), Methodologies for estimating air pollutant emissions from ships (Trozzi C., Vaccaro R., 2006), Climate change and maritime security (Basil Germond, 2019), Strategies to Reduce Air Pollution in Shipping Industry (Han, Chul-hwan, 2010),

In this paper, the writer uses mixed methods (quantitative and qualitative methods). For quantitative analysis, by calculating the level of KRI exhaust emissions in Koarmada B (not the real name of location). The results of the calculations are analyzed, and then a descriptive qualitative by risk management analysis approach is carried out. This paper is organized into several parts; the second part is the material and method, the third part is the research results, the fourth part is the discussion, and finally, the fifth part is the conclusion.

2. MATERIAL AND METHOD

2.1 Air Pollution Hazard

Exhaust gas emissions as a cause of air pollution, in excess concentrations, can have a detrimental impact on human life, causing health problems and damage to the environment. Some of the negative impacts that exhaust gas emissions with excess concentrations can cause include:

a. CO2 (Carbon Dioxide)

The remainder of the combustion is in the form of CO2 or also known as carbon dioxide, which is a greenhouse gas that can cause environmental damage. Indeed, CO2 emissions from shipping activities are estimated to account for 3-5% of total CO2 emissions (see for example IMO, 2009). In addition, estimates show that in 2050 maritime transport will be responsible for 15% of total CO2 emissions.

b. Sulphur Dioxide (SO2)

Pollution caused by sulphur oxides is caused by sulphur components in the form of a colourless gas, namely Sulphur Dioxide (SO_2) and Sulphur Trioxide (SO_3), both of which are known as sulphur oxides (SO_x). The impact of SO_x pollutants on humans is the irritation of the respiratory system. Several studies have shown that throat irritation can occur at SO_2 concentration levels of 5 ppm or more; there are even more sensitive individuals where irritation can occur at concentrations of 1-2 ppm. SO_2 is often referred to as a pollutant that is harmful to human health, especially in the elderly and people with chronic diseases of the cardiovascular, respiratory system.

c. Carbon Monoxide (CO)

Carbon monoxide is a compound that is odorless, tasteless, and at normal air temperature conditions in the form of a colorless gas. Unlike other compounds, CO has the potential to be harmful because it can form strong bonds with the blood pigment, namely hemoglobin.

d. Nitrogen Dioxide (NO_2)

NO_2 is toxic, especially to the lungs. NO_2 levels above the 100 ppm concentration level can kill most experimental animals, and 90% of these deaths are caused by symptoms that arise, namely pulmonary edema (pulmonary edema). NO_2 levels of 800 ppm can result in 100% of the deaths in the tested animals in less than 29 minutes. Experiments with the use of NO_2 at a concentration level of 5 ppm within 10 minutes tested on humans resulted in the person experiencing shortness of breath.

e. Hydro Carbon (HC)

The hydrocarbons in the air will react with other materials and form a new band called Polycyclic Aromatic Hydrocarbon (PAH). This substance is found in many industrial and traffic-heavy areas. If the PAH substance enters the lungs, it can cause injury and trigger the growth of cancer cells.

f. Suspended Particulate Matter (SPM)

In general, the particulate dust size of about 5 microns is an airborne particulate that is harmful to humans because it can be inhaled directly into the lungs and settles in the alveoli. However, it does not mean that particulate sizes of more than 5 microns are harmless; instead, larger particulates can disrupt the upper respiratory system causing serious irritation symptoms.

g. Lead (Pb)

High levels of lead (Pb) in the air can interfere with the formation of red blood cells. Early symptoms due to poisoning are shown by disruption in the function of the enzymes that form red blood cells, which in turn leads to symptoms of other health problems such as anemia, kidney damage, brain disorders, and others, exacerbated by the occurrence of lead (Pb) poisoning. Accumulative.

In addition to several negative impacts that have a direct impact on human health, exhaust emissions also harm the environment, such as global warming, which has a very broad effect, including causing storms, droughts, floods, melting of the north and south polar ice which causes sea levels to rise—causing tidal flooding, to forest fires. Furthermore, emissions from ships are transported in the atmosphere over several hundreds of kilometres, and thus can contribute to air quality problems on land even if they are emitted at sea. This pathway is especially relevant for the deposition of sulphur and nitrogen compounds (Cofala et al., 2007). Another impact on the maritime security sector, according to Basil Germond (2019), states that climate change due to global warming affects the level of maritime security of a country's territory.

2.2 Calculation of Exhaust Gas Emissions According to Marpol Annex VI

The calculation of exhaust gas emissions on ships uses the ship fuel consumption calculation approach by referring to the calculation method used according to Marpol 73/78 Annex VI. The International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978) represents the main IMO Convention currently in force regarding the protection of the marine environment. The MARPOL 1973/1978 Convention represents the most relevant regulation on marine pollution. In 1997, air pollution was included in Annex VI, setting limits on sulphur oxide (SOx) and nitrogen oxide (NOx) emissions from ship exhausts and prohibiting deliberate emissions of ozone-depleting substances. Annex VI was ratified by 60 contracting States with 84.04% of the world's merchant shipping tonnage. It entered into force on 19 May 2005. In 2008 Annex VI was amended (MEPC 58/23/Add.1). The revised text, which establishes more stringent emission requirements for ships that operate in designated coastal areas where air quality problems are acute, entered into force on 1 July 2010.

The IMO emission standards are commonly referred to as Tier I-III standards. IMO divides the formulation of NOx emissions into 3 calculation methods by classifying them based on the year of manufacture of the engine with the terms Tier I, Tier II, and Tier III. The division into 3 Tier, namely:

a. Tier I: diesel engines (> 130 kW) installed on ships built on or after January 1, 2000, and before January 1, 2011.

b. Tier II: diesel engines (> 130 kW) installed on ships built on or after January 1, 2011, and before January 1, 2016.

c. Tier III: diesel engines (> 130 kW) installed on ships built on or after January 1, 2016.

For calculating the value of pollutant emission, it is necessary to know the NOx Threshold Value and the Pollutant Emission Factor. The NOx threshold values regulated in the Marpol 73/78 Annex VI regulations amended in October 2008 are grouped based on engine speed (rpm) are shown in table 2.1. Pollutant emission factors on ships using marine diesel oil / marine gas oil are shown in table 2.2. According to Carlo Trozzi (2006) in the International Transport and Environment seminar held in France, to calculate the emission value of pollutants with a numerical approach, we can use the equation:

$E_i = \sum_m (FC_m \, x \, EF_{i,m})$ ………………………(2.1)

Where:

E_i = Pollutant Emissions i (kg)

FC_m = Fuel consumption (ton/hour)

$EF_{i,m}$ = Pollutant Emission Factor (kg/ton)

m = Fuel type

Table 2.1 Pollutant Emission Threshold Value

Regulation	NO_x limit	(revolution per minute)
Tier I	17 g/kWh	$n < 130$
	$45 \times n^{-0.2}$ g/kWh	$130 \le n < 2000$
	9.8 g/kWh	$n \ge 2000$
Tier II	14.4 g/kWh	$n < 130$
	$44 \times n^{-0.23}$ g/kWh	$130 \le n < 2000$
	7.7 g/kWh	$n \ge 2000$
Tier III	3.4 g/kWh	$n < 130$
	$9 \times n^{-0.2}$ g/kWh	$130 \le n < 2000$
	2 g/kWh	$n \ge 2000$

(Source : MARPOL IMO ANNEX VI)

Table 2.2 Pollutant Factor Value

	Code	Name			
NFR Source Category	1.A.3.d.i	International navigation			
	1.A.3.d.ii	National navigation			
	1.A.4.c.iii	Agriculture / forestry / fishing: National fishing			
	1.A.5.b	Other, mobile (including military, land based and recreational boats)			
Fuel	Marine diesel oil/marine gas oil (MDO/MGO)				
Not applicable	HCH				
Not estimated	NH3				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NOx	78.5	kg/tonne fuel	0	0	Entec (2007). See also note (2)
CO	7.4	kg/tonne fuel	0	0	Lloyd's Register (1995)
NMVOC	2.8	kg/tonne fuel	0	0	Entec (2007). See also note (2)
SOx	20	kg/tonne fuel	0	0	Note value of 20 should read 20*S. Lloyd's Register (1995). See also note (1)
TSP	1.5	kg/tonne fuel	0	0	Entec (2007)
PM10	1.5	kg/tonne fuel	0	0	Entec (2007)
PM2.5	1.4	kg/tonne fuel	0	0	Entec (2007)
Benzo(b)fluoranthene	0.01	g/tonne fuel			average value
Benzo(k)fluoranthene	0.01	g/tonne fuel			average value
Benzo(a)pyrene	0.002	g/tonne fuel			average value
Indeno(1,2,3-cd)pyrene	0.001	g/tonne fuel			average value
Pb	0.13	g/tonne fuel	0	0	average value
Cd	0.01	g/tonne fuel	0	0	average value
Hg	0.03	g/tonne fuel	0	0	average value
As	0.04	g/tonne fuel	0	0	average value

(Source : EMEP/EEA Air Pollutant Emission Inventory Guidebook, 2019)

2.3 Risk Management

Risk management is defined as a science that discusses how an organization determines its size in mapping an existing problem by placing various management approaches that are carried out comprehensively and systematically (Fahmi, 2010). Risk is uncertainty about future events, or risk is a form of uncertainty about a situation that will occur later (in the future) with decisions taken based on various considerations at this time (Griffin, 1996).

(Bhoola, 2014) divides risk response into four strategic forms, namely avoidance, transference, mitigation, and acceptance. Briefly, it can be explained as follows:

a. Avoidance

Avoidance strategies are carried out by reducing or eliminating activities that have a high likelihood of risk by making it more difficult for these risks to occur. Avoidance can also be done by doing work by avoiding risky activities but with the same ultimate goal.

b. Transference

Transference strategy is carried out by transferring part or all of the risk to third parties. Usually, the transferred risk is low but has a considerable financial effect. In the process, it is necessary to carry out a more in-depth assessment of the third party regarding managing work and the risks that may occur.

c. Mitigation

Mitigation strategies are carried out by analyzing the potential and impact of risks, then planning to reduce the possibility and effects of these risks within the company's capabilities.

d. Acceptance

Realizing that some risks still exist, the acceptance strategy is carried out by accepting existing risks by providing allocations or leeway in schedules and costs, but these allocations need to be ensured and monitored so that they do not exceed the planned value.

OHSAS 18001 applies risk control guidelines specified in the K3 field with control groupings, namely elimination, substitution, engineering control, administrative control, and the use of Personal Protective Equipment (PPE). Following the objectives of Risk Control, namely to minimize the level of risk from an existing hazard, according to the AS / NZS 4360 (2004) standard, risk control is generally carried out with the following approach:

a. Avoid risk (risk avoid)

b. Reducing the possibility of this happening (reduce likelihood).

c. Reducing the consequences of events (reduce consequence)

d. Transfer of risk to other parties (risk transfer)

e. Bear the remaining risk (residual risk).

2.4 Method of Research

This research following step which is shown in the flow chart diagram shown in figure 2.

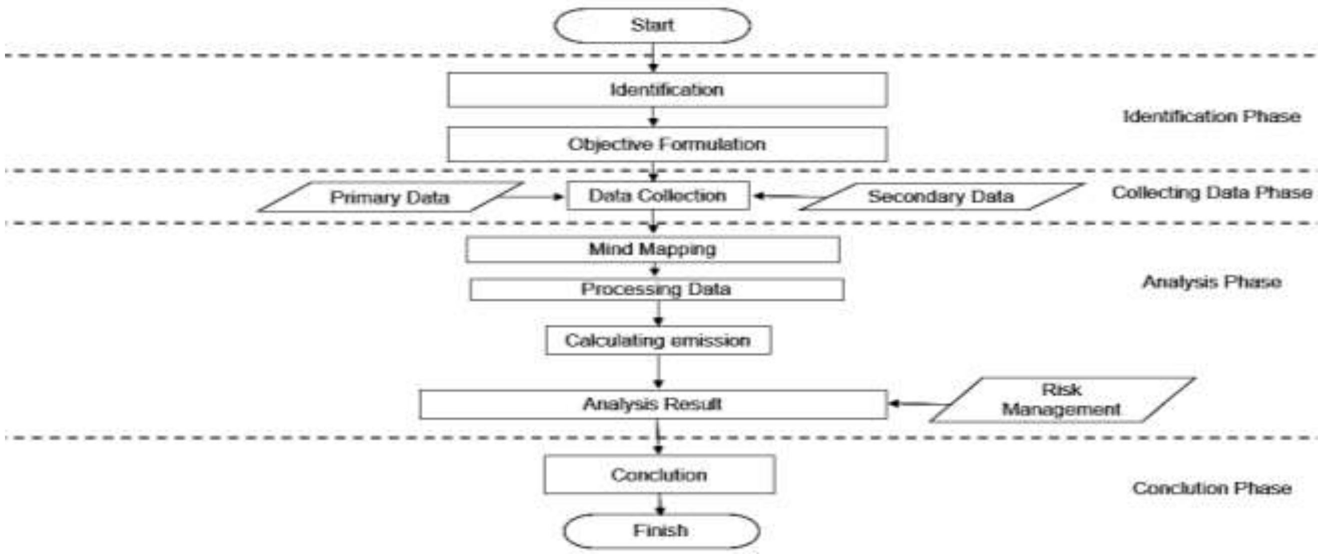

Figure 2. Research Flowchart

3. RESULT AND DISCUSSION

3.1 Data Collection

Analyzing process the main problems in this study, data collection includes:

a. Primary data collection includes data on engine characteristics, year of manufacture, and its relation to fuel use and exhaust emissions produced;

b. Secondary data collection includes data from related sources.

In collecting data to obtain information, literature studies and interviews with related parties were carried out to obtain the required data. To maintain data confidentiality, the name KRI is disguised but does not change the essence of the importance of presenting the data.

In table 3.1, fuel consumption data is presented from the KRI element Koarmada B.

Table 3.1 Fuel Consumption Data

NO	NAME OF KRI	POWER	FUEL CONSUMPTION		NO	NAME OF KRI	POWER	FUEL CONSUMPTION		NO	NAME OF KRI	POWER	FUEL CONSUMPTION	
		(KW)	l/h	Kg/h			(KW)	l/h	Kg/h			(KW)	l/h	Kg/h
1	A	781	85	72,25	21	U	420	84	71,4	41	PP	148	30	25,5
2	B	781	85	72,25	22	V	495	75	63,75	42	QQ	148	62,5	53,125
3	C	500	62,5	53,125	23	W	495	75	63,75	43	RR	200	80	68
4	D	500	104,79	89,0715	24	X	495	75	63,75	44	TT	200	80	68
		292	62,5	53,125	25	Y	232	50	42,5	45	UU	100	35	29,75
5	E	500	78	66,3	26	Z	312	50	42,5	46	VV	100	35	29,75
6	F	500	104,79	89,0715	27	AA	232	50	42,5	47	YY	200	50	42,5
7	G	500	62,5	53,125	28	BB	232	62,5	53,125	48	XX	140	25	21,25
		715	104,16	88,536	29	CC	232	62,5	53,125	49	YY	140	25	21,25
8	H	500	100	85	30	DD	256	45	38,25	50	ZZ	125	25	21,25
9	I	600	110	93,5	31	EE	500	80	68	51	AAA	125	25	21,25
10	J	500	100	85	32	FF	500	80	68	52	BBB	168	35	29,75
11	K	500	124	105,4	33	GG	292	40	34	53	CCC	150	35	29,75
12	L	292	54,16	46,036	34	HH	292	40	34	54	DDD	150	35	29,75
13	M	292	54,16	46,036	35	JJ	292	40	34	55	EEE	292	95	80,75
14	N	292	54,16	46,036	36	KK	164	35	29,75	56	FFF	159	62,5	53,125
15	O	292	54,16	46,036	37	LL	164	35	29,75	57	GGG	125	25	21,25
16	P	292	50	42,5	38	MM	64	30	25,5	58	HHH	500	80	68
17	Q	313	50	42,5	39	NN	64	30	25,5	59	III	800	92	78,2
18	R	313	50	42,5	40	OO	64	30	25,5	60	JJJ	270	62,5	53,125
19	S	292	50	42,5	43	RR	200	80	68	61	KKK	500	42	35,7
20	T	420	84	71,4	44	TT	200	80	68	62	LLL	300	50	42,5
										63	MMM	500	58	49,3
										64	NNN	500	42	35,7

3.2 Data Processing

Direct measurement of exhaust emission levels is considered impractical or even impossible to do for every pollutant source due to the absence of a ship exhaust emission measurement tool within the Indonesian Navy. Therefore an approach is formulated to estimate the amount of pollution load using equation 2.1. For example, the calculations on KRI A and KRI H to get the value of exhaust emissions are carried out in the following steps:

a. Convert fuel consumption from l / h to kg / h

Assuming the density of the fuel used is 0.85 kg / l,

- KRI A : 85 l/h x 0,85 kg/l = 72,25 kg/h
- KRI H : 100 l/h x 0,85 kg/l = 85 kg/h

b. Calculating the value of exhaust gas emissions with a formula

$$E_i = \sum_m (FC_m \, x \, EF_{i,m})$$

With the NOx pollutant factor value according to table 2.2 is 78.5 kg / ton, then,

- KRI A :

E_i = 72,25 x 10^{-3} ton/h x 78,5 kg/ton

= 5,671 kg/h

with 781 kW engine power, the emission value exhaust gas is obtained:

E_i = 5,671 kg/h : 781 kw

= 0,00726 kg/kwh

= 7,26 g/kwh

- KRI H :

E_i = 85 x 10^{-3} ton/h x 78,5 kg/ton

= 6,6725 kg/h

with an engine power of 500 kw the emission value exhaust gas is obtained:

E_i = 6,6725 kg/h : 500 kw

= 0,013345 kg/kwh

= 13,345 g/kwh

c. Calculate emission threshold values

- KRI A :

The engine made in 2014 with an engine speed of 1800 rpm, so Tier II with an emission limit formula is used:

44 x $n^{-0,23}$ g/kwh

= 44 x $1800^{(-0,23)}$ g/kwh

= 7,847 g/kwh

- KRI H :

The engine made in 2007 with an engine speed of 1800 rpm, then the Tier I formula is used with the emission limit formula:

45 x $n^{-0,2}$ g/kwh

= 45 x $1800^{(-0,2)}$ g/kwh

= 10,049 g/kwh

For the other KRI elements, Results of the calculations are presented in the table 3.2.

Table 3.2 Emission Level Calculation Result Data

NO	NAME OF KRI	NOx Emission Value	Limit	NO	NAME OF KRI	NOx Emission Value	Limit
		g/kwh	g/kwh			g/kwh	g/kwh
1	A	7,262003841	7,847657	32	FF	10,676	10,42304
2	B	7,262003841	7,847657	33	GG	9,140410959	7,847657
3	C	8,340625	10,04981	34	HH	9,140410959	7,847657
4	D	13,9842255	10,04981	35	JJ	9,140410959	7,847657
		14,28189212	10,04981	36	KK	14,24009146	8,183737
5	E	10,4091	10,04981	37	LL	14,24009146	8,183737
6	F	13,9842255	10,04981	38	MM	31,27734375	10,42304
7	G	8,340625	10,04981	39	NN	31,27734375	10,42304
		9,720386014	10,04981	40	OO	31,27734375	10,42304
8	H	13,345	10,04981	41	PP	13,52533784	10,42304
9	I	12,23291667	10,04981	42	QQ	28,17778716	8,183737
10	J	13,345	10,04981	43	RR	26,69	10,0498
11	K	16,5478	10,04981	44	TT	26,69	10,0498
12	L	12,37611644	10,04981	45	UU	23,35375	10,0498
13	M	12,37611644	10,04981	46	VV	23,35375	10,0498
14	N	12,37611644	10,04981	47	YY	16,68125	2,084607
15	O	12,37611644	10,04981	48	XX	11,91517857	8,183737
16	P	11,4255137	10,42304	49	YY	11,91517857	8,183737
17	Q	10,65894569	10,42304	50	ZZ	13,345	10,04981
18	R	10,65894569	10,42304	51	AAA	13,345	10,04981
19	S	11,4255137	10,42304	52	BBB	13,90104167	10,04981
20	T	13,345	10,42304	53	CCC	15,56916667	10,04981
21	U	13,345	10,42304	54	DDD	15,56916667	10,04981
22	V	10,10984848	2,009963	55	EEE	21,70847603	10,04981
23	W	10,10984848	2,009963	56	FFF	26,2283805	10,04981
24	X	10,10984848	2,009963	57	GGG	13,345	10,04981
25	Y	14,38038793	10,42304	58	HHH	10,676	10,42304
26	Z	10,69310897	10,42304	59	III	7,673375	8,183737
27	AA	14,38038793	10,42304	60	JJJ	15,44560185	10,42304
28	BB	17,97548491	10,42304	61	KKK	5,6049	7,847657
29	CC	17,97548491	10,42304	62	LLL	11,12083333	10,42304
30	DD	11,72900391	10,42304	63	MMM	7,7401	10,04981
31	EE	10,676	10,42304	64	NNN	5,6049	7,847657

Based on the data from table 3.2 it can be seen that of the 64 KRIs in Koarmada B, 56 KRIs have passed the allowable exhaust emission limits and only 8 KRI are still within the tolerance value for exhaust gas emission levels or as much as 87.5% of the KRI in Koarmada. B has exceeded the exhaust gas emission limit and only 12.5% is still within the allowable emission tolerance value (Figure 3.1).

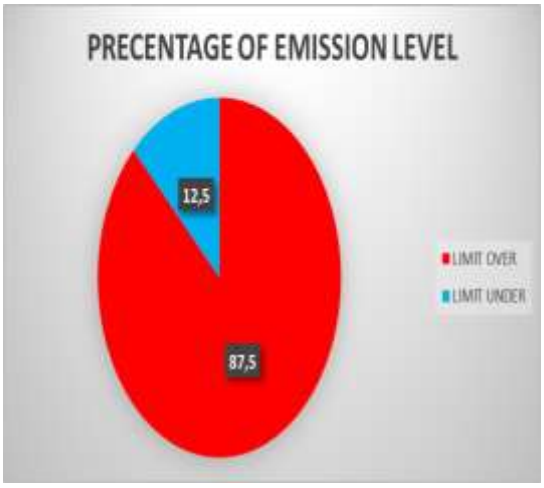

Figure 3.1 Percentage of emission level KRI exhaust gases

Based on the value of exhaust gas emission levels in KRI, most of which have exceeded the permitted emission limits, KRI can be considered as a source of air pollutants. Given that the impact that air pollution can cause is very dangerous for the environment and human health, with a risk control approach, what the Indonesian Navy can do is take risk control steps as a risk response according to the theory presented by Bhoola (2014) where risk response divided into 4 forms of strategy, namely avoid (avoidance), transfer (transference), mitigation (mitigation) and accept (acceptance). The strategy of avoiding risk and transferring risk, in this case, cannot be done because the need for the Indonesian Navy to continue operating is high. As for the transfer strategy, in the context of this risk, it cannot be done because the risk that occurs is not transferable. What can be done in controlling the risk of this case is to mitigate risks by reducing the impact of a higher level of risk, such as using environmentally friendly fuels, replacing conventional engines with modern engines that are more environmentally friendly, providing training to ship crews so they can carry out procedures operation and maintenance of machines. Furthermore, if risk mitigation steps have been taken, with the existing risk severity, a relatively smaller risk can be accepted. However, steps and strategies in risk control need to be carried out through further studies adapted to the situation and conditions in the Indonesian Navy so that maximum results can be obtained to obtain the best solution in risk mitigation.

4. CONCLUSIONS

Based on the results of the research that has been done, it can be concluded that most of the KRI in Koarmada B has exceeded the allowable exhaust gas emission limit so that it can be considered that KRI is one of the sources of air pollutants. Considering the impact of the dangers that can arise from air pollution, which is damaging to the environment and health, the Indonesian Navy needs to carry out risk control as a concrete step to reduce air pollution due to KRI exhaust emissions. Several strategies need to be made to deal with this.

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