QUANTITATIVE RISK ASSESSMENT OF CITY GAS NETWORK AT DEPOK, WEST JAVA

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Abstract- A City Gas Network has, commonly, a potential in an accident of fire and explosion risks. To date, the extend of risk of city gas network located in Depok, west Java hasn't yet be taken into account.The aim of the research is to count the risk by methodof quantitative risk assessment. This assessment is performed by determination of the failure frequency, by consequence analysis using ALOHA Software, and by evaluating the risk magnitude that is categorizedaccording to the UK Health and Safety Executive (UK-HSE) standard criteria. So, the gas network risk mitigation can be recommended accurately based on the cost-benefit analysis with the disproportion factor less than or equal to 10.The results from the risk evaluationshowed that the individual risk in each of 28 nodes in thegas pipeline network observed in Depok is categorized wholly in category II (i.e tolerable if ALARP).Furthermorethe result of societal risk evaluation according to UK-HSE F-N Curve is also confirmed in category II. So,in order to achieve ALARP, it isrecommended, especially, to prevent the possiblities of leaked gas indoor accumulation bythe installation of rooftop turbineventilator at Metering Regulating Station (node 3). The other of gas station, the periodic patrols and visual inspections should be carried out for all pipeline nodes.

Index Terms- Node, Individual Risk, Societal Risk, ALARP

I. INTRODUCTION

Recently, the Indonesian government policyhas urged to employa natural gas as a city gas for household needs. The area of Depok City, West Java which is a densely enough population,is one of the cities that have utilized the city gas for household needs through a pipeline network managed by PT XY.The city gas carried in the pipeline network is a gaswhose composition is dominated by hydrocarbon compounds of methane, ethane,and propane that are flammable and explosive substances. If there is an accident of fire and/or explosion, then many people present or resides around the city gas network areawill be prone to exposed to the risk of fatality.Indeed, up to now,therehasbeen no explosion or fire accident of the Depok city gas network, but it should beawareness.The historical data around the world shows that the potential hazardof the city gas network is obviously recorded to be considered seriously. On September 9, 2010, natural gas transmission pipeline ruptured resulting in a fire that destroyed 38 homes, killed eight people and many were injured [1]. On December 11, 2012, a buried natural gas transmission pipeline ruptured followed by immediately ignition causingthree houses were destroyed and several others were damaged [2]. On August 2, 2017, a building at the Minnehaha Academy in Minneapolis, Minnesota was destroyed by a natural gas explosion because of hot tapping error causing two fatalities and nine injuries [3]. Such accidents maybe occur at the Depok city gas network and the potential risk of fire and explosion have not yet be studied in detail.The aim of the research is to quantify the risk by quantitative risk assessment (QRA).

QRA is one of the safety assessment methods that would help predict regions where such accidents likely to occur by quantifying its risk. Generally, this assessment is performed by determination of the failure frequency, by consequence analysis using ALOHA Software, and by evaluating the risk magnitude that is categorized according to the UK Health and Safety Executive (UK-HSE) standard criteria.

II. METHODOLOGICAL APPROACH

The scope of the research object is focused in the pipeline network from the 16 inch tapping point of transmission pipeline (17 bar) until to the loop header pipeline network (3.7 bar) as the process flow diagram presented in Figure 1.To reduce the pressure from 17 bar to 3.7 bar, regulator at Metering Regulating Station (MR/S) is designed to be two stage regulating step: high pressure (HP) regulator and middle pressure (MP) regulator.

The step of QRA could be described below.

A. Nodes Allocation

A node is a part of a gas pipeline network system that has specific functions and characteristics.The determination of a node is based on the functions and characteristics namely gas pressure, pipe size, pipe material, pipe fitting, construction (above ground or underground), andisolatable (with block valves) part. For example, the Loop Header A in the pipeline network is defined as a node because this loop has a burden pressure of 3.7 bar and the material fabricated for this loop is MDPE 180 mm. The other example node is Loop Header B to be allocated separately because the Loop Header B is arranged in the condition of isolated pipeline from the Loop Header A by block valves. The efforts of node allocation in this research will simplify in data processing, so that the each part of

pipeline network could be ascertained accurately for its individual risk.

B. Hazard and Scenario Identification

The principal hazard is the unintentional ignition of the

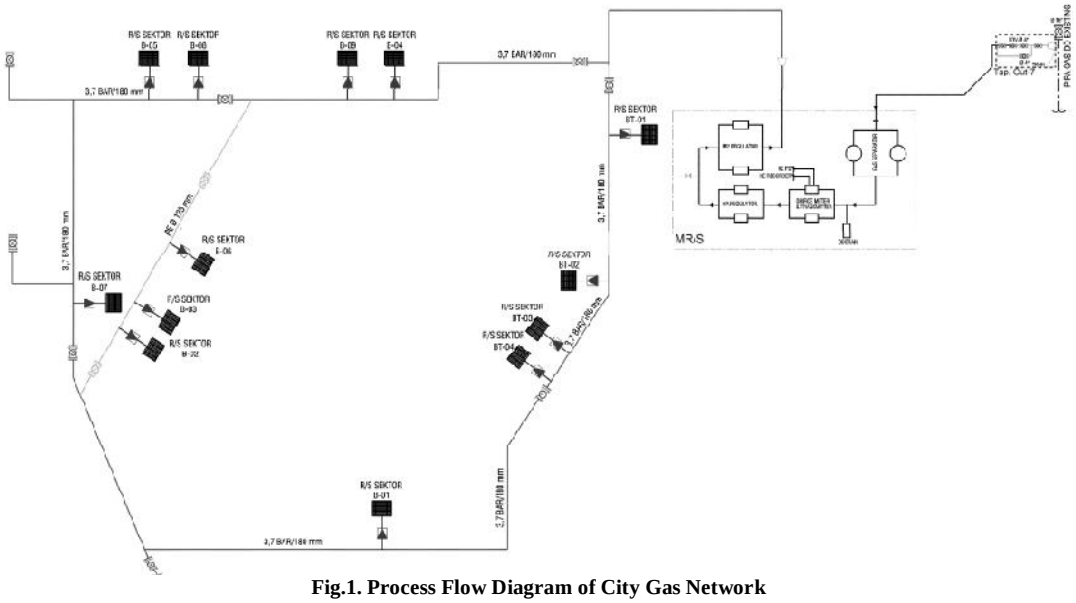


Fig.1. Process Flow Diagram of City Gas Network

leaked gas from city gas network and the output from the QRA is, therefore, the risk of an ignited leaked gas affecting members of the public [4]. The ignited flammable and explosive city gas causes the outcomes of jet fire and vapor cloud explosion (VCE). These outcomes are taken credit for the risk counting. The un-ignited leaked gas causes the outcome of material and this outcome isn't taken a credit for toxic gas dispersion because the city gas is non-toxic gas.

C. Failure Frequency Analysis

Failure frequency analysis will quantify the annual frequency of each outcome in each node through ETA (Event Tree Analysis) Diagram. Initiating event of ETA is a loss of containment. The annual failure frequency of each outcome will be calculated by multiplying the annual frequency of loss of containment andthe probability of each pivotal event.

The annual frequency of loss of containment is calculated based on EGIG (European Gas Pipeline Incident Data Group) database for pipeline part and IOGP (International Association of Oil & Gas Producers) database for non-pipeline part [5]-[6].

D. Consequences Analysis

Each outcome will be modeled with ALOHA 5.4.5 Software by inputting gas composition data, geographical conditions (wind speed, temperature, humidity etc.), pipe dimensions, operating conditions (pressure and temperature). ALOHA will produce output in the form of threat zone within cartesiandiagram representing LOC (Level of Concern) seen from the side of overpressure, and thermal radiation.

LOC of overpressure from VCE is 3 psi and LOC of radiation from jet fire is 12.5 kW/m^2 that each has the effect of fatality. For effect of serious injury, the LOC is 2 psi and 4.9 kW/m^2 respectively for overpressure and radiation [7].

E. Risk Evaluation

The results of QRA are in the form of individual risk and societal risk. The magnitude of the risk will be evaluated according to the UK Health and Safety Executive Standards (UK-HSE) standard criteria. Thus, the need for mitigation measures can be determined accurately after they are evaluated.

The individual risk is the annual frequency of a fatality at a location where the outcome is lethal and the evaluation will be based on Table 1.The risk is obtained from the sumof the annual frequency of jet fire and VCE outcome with death probability is 100% and the probability of people in the threat zone is 100%. When the multiple fatalities become a concern, the societal risk is defined as the relationship between the annual frequency of an outcome and number of fatality and the evaluation will be based on Figure2. It is expressed in the form of F-N Curve. A number of fatalities in each outcome will be calculated simply from the multiplication of the area produced from the threat zone and population density of 10,255 people/km^2 [10].

Table 1. Individual Risk Criteria [8]

Frequency (per year)	Category	Remark
> 1x10^{-4}	I	Intolerable
1x10^{-6} to 1x10^{-4}	II	Tolerable ifAs Low As Reasonably Practicable/ ALARP
< 1x10^{-6}	III	Negligible

Table 2. Frequency of Loss of Containment Calculation on Non-Pipeline Part

Item Detail	Node 1	Node 3	Node 4-11	Node 12-13	Node 14-22
Flange 16"	3	-	-	-	-
Flange 4"	11	1	-	-	-
Flange 3"	-	45	-	-	-
Flange 180 mm	-	-	2	-	4
Flange 125 mm	-	-	-	2	-
Ball Valve 16"	1	-	-	-	-
Ball Valve 4"	4	-	-	-	-
Ball Valve 3"	-	17	-	-	-
Ball Valve 2"	-	-	-	-	1
Ball Valve 1/2"	3	26	-	-	-
Ball Valve 180 mm	-	-	1	-	-
Ball Valve 125 mm	-	-		1	-
Instrument Connection	3	38	-	-	-
Filter	-	6	-	-	-
Check Valve 3"	-	4	-	-	-
Regulator Valve 1"	-	8	-	-	1
Relief Valve 1"	-	4	-	-	-
ESDV-Ball Valve 4"	1	-	-	-	-
Frequency of Loss of Containment (/year)	2.18×10^{-3}	2.74×10^{-2}	2.35×10^{-4}	1.56×10^{-4}	3.97×10^{-4}

Table 3. Frequency of Loss Containment Calculation on Pipeline Part

Causes	Node 2	Node 23-27	Node 28
External interference	8.54×10^{-6}	1.07×10^{-5}	1.07×10^{-5}
Corrosion	6.80×10^{-6}	1.00×10^{-6}	1.00×10^{-6}
Construction defect/Material Failure	3.74×10^{-6}	1.01×10^{-4}	1.01×10^{-4}
Hot tap made by error	6.57×10^{-6}	1.45×10^{-4}	1.45×10^{-4}
Ground movement	1.32×10^{-5}	4.82×10^{-5}	4.82×10^{-5}
Other and unknown	1.36×10^{-6}	3.05×10^{-4}	3.05×10^{-4}
Frequency of Loss of Containment (/year)	4.02×10^{-5}	6.10×10^{-4}	6.10×10^{-4}

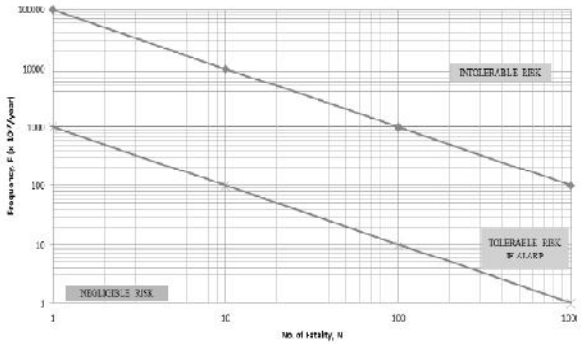


Fig.2. F-N Curve of Societal Risk Criteria [9]

F. Cost-Benefit Analysis

When the calculated risk is in category II, the recommendation to reduce the risk is done by taking into account the costs incurred compared to the benefit gained through the CBA (Cost-Benefit Analysis).The CBA helps in making a decision whether a recommendation for further risk reduction is reasonably practicable. A recommendation is included as reasonably practicable if the Disproportion Factor (comparison between costs incurred andbenefit gained) is less than or equal to 10 [11].

III. RESULTS AND DISCUSSION

A. Individual Risk

As mention above, the annual frequency of loss of containment as initiating event is calculated based on EGIG and IOGP database. The raw data from both will be screened according to nominal diameter, depth of cover, nominal wall thickness, and material grade, so the result is as presented inTable 2 and Table 3. Then, ETA diagram is constructed to achieve an annual frequency of each outcome in each node. Generally, ETA diagram is presented in Figure 3.

Table 4. The result of Individual Risk Calculation

Node	Description	Pressure	Material	Individual Risk (/year)
1	Tap. Out-7	17 bar	CS 4 inch	7.93×10^{-5}
2	Tap. Out-7 Discharge Line	17 bar	CS 4 inch	6.84×10^{-6}
3	MR/S	17 bar	CS 3 inch	4.26×10^{-5}
4	Block Valve V-01	3.7 bar	MDPE 180 mm	4.01×10^{-5}
5	Block Valve V-02	3.7 bar	MDPE 180 mm	4.01×10^{-5}
6	Block Valve V-03	3.7 bar	MDPE 180 mm	4.01×10^{-5}
7	Block Valve V-04	3.7 bar	MDPE 180 mm	4.01×10^{-5}
8	Block Valve V-05	3.7 bar	MDPE 180 mm	4.01×10^{-5}
9	Block Valve V-06	3.7 bar	MDPE 180 mm	4.01×10^{-5}
10	Block Valve V-07	3.7 bar	MDPE 180 mm	4.01×10^{-5}
11	Block Valve V-08	3.7 bar	MDPE 180 mm	4.01×10^{-5}
12	Block Valve V-09	3.7 bar	MDPE 125 mm	2.66×10^{-5}
13	Block Valve V-10	3.7 bar	MDPE 125 mm	2.66×10^{-5}
14	R/S Sektor BT-01	3.7 bar	CS 3 inch	6.76×10^{-5}
15	R/S Sektor BT-02	3.7 bar	CS 3 inch	6.76×10^{-5}
16	R/S Sektor BT-03 & BT-04	3.7 bar	CS 3 inch	6.76×10^{-5}
17	R/S Sektor B-01	3.7 bar	CS 3 inch	6.76×10^{-5}
18	R/S Sektor B-07	3.7 bar	CS 3 inch	6.76×10^{-5}
19	R/S Sektor B-05 & B-08	3.7 bar	CS 3 inch	6.76×10^{-5}
20	R/S Sektor B-09 & B-04	3.7 bar	CS 3 inch	6.76×10^{-5}
21	R/S Sektor B-02 & B-03	3.7 bar	CS 3 inch	6.76×10^{-5}
22	R/S Sektor B-06	3.7 bar	CS 3 inch	6.76×10^{-5}
23	Loop Header A	3.7 bar	MDPE 180 mm	5.19×10^{-5}
24	LoopHeader B	3.7 bar	MDPE 180 mm	5.19×10^{-5}
25	LoopHeader C	3.7 bar	MDPE 180 mm	5.19×10^{-5}
26	LoopHeader D	3.7 bar	MDPE 180 mm	5.19×10^{-5}
27	LoopHeader E	3.7 bar	MDPE 180 mm	5.19×10^{-5}
28	LoopHeader F	3.7 bar	MDPE 125 mm	5.19×10^{-5}

*CS: Carbon Steel; MDPE: Medium-Density Polyethylene

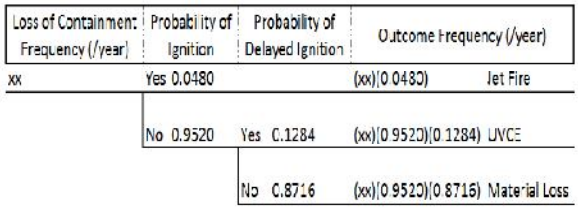


Fig.3. ETA Diagram

The calculation above shall be considered the existing safeguards below:

1) Insulation joint at the transition between aboveground and underground carbon steel pipe to prevent corrosion at the aboveground part. The probability failure of isolation joint is 0.1131 [12]. Gas Detection System (Gas Detector and Alarm) at Metering Regulating Station (MR/S). The probability failure of this system is 0.0935 [13]-[14].
2) Portable fire extinguisher at MR/S. Note: Portable fire extinguisher can be obtained easily; people who use portable fire extinguisher know how to use it;it can be operated well.The probability of immediately fire extinguishment using the portable fire extinguisher is 0.49 [15].
3) Underground tape marker where is placed beyond slab. It can obtain 60% reduction in external interferencefailure frequency [16].
4) The slababove soil cover beyond underground pipe. It can reduce the frequency of construction defect/material failure to negligible [16].

The result of individual risk calculation is listed inTable 4. In this result of calculation, double jeopardy (concurrent outcomes from different node revealed failures) is not considered [17]. All node is categorized in category II (tolerable if ALARP).

B. Societal Risk

Each outcome on Table 4 is plotted on F-N Curve with its number of a fatality resulting ina pattern in Figure 4. It is seen that most of the node lies in category II (tolerable if ALARP).

C. ALARP Demonstration

Both of the calculated risks are in category II. Thus, ALARP demonstration is carried out to achieve ALARP. Three recommendations will be analyzed through CBA.

The first one is installation rooftop turbine ventilator at MR/S so when there is a lighter than air-gas leakage, the gas will not be accumulated and vapor cloud explosion can be prevented. Its probability of failure is 0.06 [18]. The node which is influenced by this recommendation is node 3.The ETA diagram for this

recommendation is presented in Figure 5. From the ETA diagram,the residual riskof node 3 is 9.23 x 10^{-6}/year and the risk reduction is 3.33 x 10^{-5}/year.

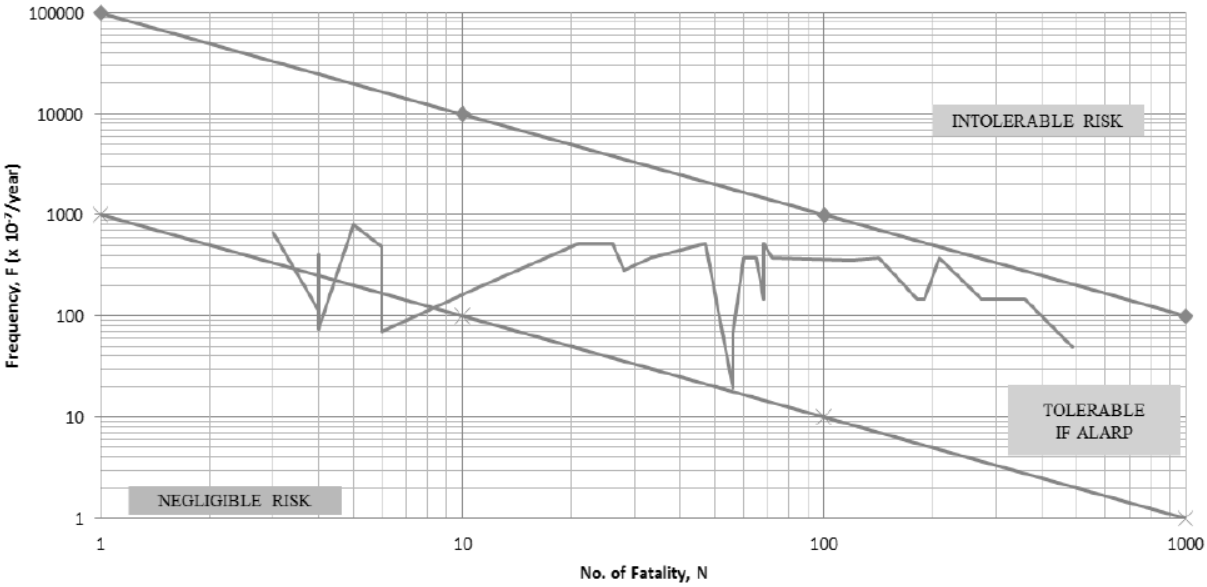


Fig.4.F-N Curve of Societal Risk Calculation

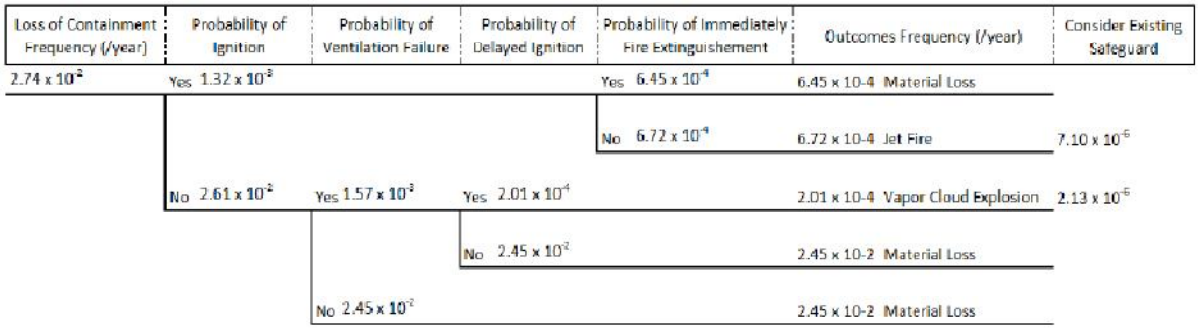


Fig.5. ETA Diagram for Adding Rooftop Turbine Ventilator at MR/S

The number of fatalities and serious injury from the current node 3 is respectively 131 and 252. Based on the regulation of Indonesian Government, warranty fee for fatality and serious injury are respectively IDR 36,000,000 and IDR 200,743,216 [19]-[21]. With the lifetime of the network pipe is 20 years, so the total benefit gained is IDR 36,861,969. This value is obtained from the multiplication of the risk reduction, the sum of warranty fee of fatality and serious injury, and a lifetime of the network pipe. With the total volume of 49 m^3, MR/S building is designed to be provided by 2 turbine ventilators with a suction flow rate of 42.39 m^3/minute [22]. The total incurred cost which is obtained from the sum of purchased equipment cost and its installation cost (40% of equipment cost [23]) is IDR 2,800,000 [24]. Thus, the Disproportion Factor is 0.08 and the recommendation is reasonably practicable.

The second recommendation is adding portable fire extinguisher at each R/S. The probability of immediately fire extinguishment using the portable fire extinguisher is 0.49 with a note of portable fire extinguisher can be obtained easily, people who use portable fire extinguisher know how to use it, andit can be operated well. [15]. Risk reduction from this recommendation is 9.34 x 10^{-6} /year and the total benefit gained is IDR 800,164. The cost incurred is IDR 37,637,600 [25], so the Disproportion Factor is 47.04 and the recommendation is not reasonably practicable.

The last recommendation is periodic patrols and visual inspections (every 6 months). This activity can reduce the frequency of failure from external interference by 30% [16]. The node that provides the greatest risk reduction is Node 25. Risk reduction is 5.45 x 10^{-7} /year and the total benefit gained is IDR 1,907,611. The cost incurred is IDR 15,354,000 [26], so the Disproportion Factor is 8.05 and the recommendation is reasonably practicable.

CONCLUSION

The research has well-quantified the fire and explosion risk of city gas network at Depok City, West Java through quantitative risk assessment. The result of individual risk at each node is in category IIA

(tolerable if ALARP). The F-Ncurve of societal risk calculationpresents that most of the node lies in category II (tolerable if ALARP).The recommendations in order to achieve ALARP areinstallation of rooftop turbine ventilator at Metering Regulating Station and periodic patrols and visual inspections.

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