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Pipeline Balance and Monitoring for the Integrated Flare System in Map Ta Phut Industrial Estate

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ABSTRACT— ***This study aims to design flare pipeline network in Map Ta Phut Industrial Estate (MTP IE). This network is designed to transport waste gas from 6 companies in MTP IE to PTT LNG terminal for treatment. At typical operation case, there will be 12.46 tons/hr. of waste gas flow accumulated into the system. In an emergency case, this pipeline network is needed to handle the maximum load at 79.84 tons/hr. of waste gas, through the entire system. The difference of the mass flow rate needs the specific pipeline network design to minimize the back pressure to the system. The route of the network is selected by Google Earth to overview and to find the possible shortest way of waste gas transportation. The sizing of the pipeline system is then proposed. The flare pipeline network is designed using Aspen Flare System Analyzer program. The simulation result shows that the proposed flare pipeline network can handle all waste gas both in regular operation and in emergency cases. All plant back pressures are under the maximum allowable back pressure (MABP) limit, which means that the plant can be operated without any upset from other companies.***

Keywords— Pipeline; flare; network design; normal and emergency

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1. INTRODUCTION

Map Ta PhutIndustrialEstate (MTP IE) is the largest industrial estate in Thailand located in Rayong. More than 90 industries such as oil refinery, petrochemical, and chemical facilities with over 200 stacks are constructed and operated. There have been reported that a total of 20 different toxic chemicals were found in the MTP IE air samples at levels exceeding protective health standards in the US [1]. These chemical substances not only cause a pungent odor, but they also contribute to loan acute and long-term physical and mental health effect. Healthproblemcaused by VOCs can either be acute or chronic. This effects such as eye, nose and throat irritation, headaches, allergic skin reactions like rash, damage to heart, liver or kidneys, cancers, and damage to the central nervous system [2]. According to EIA reports, there are six companies which operate with flare system and have sufficient information for modeling. Group of companies consists of PTTAR, PTT Chemical-I1, Bangkok Synthesis (BST), HMC Polymer, Siam Polyethylene (SPE), and Thai Polypropylene (TPP). Flare system and waste gas information; both in the regular operation and the emergency cases are shown in Tables A.1 through A.6.

2. ROUTE SELECTION

The objective is to establish the shortest possible route to reduce the material and the construction cost. Construction cost and environmental impact are minimized by utilizing the existing pipeline supporter. Most of the transportation pipeline in MTP IE are constructed on the pipe rack, which designed to operate along the road in IE. After the overview, the support structure in MTP IE from "Google Earth" program, the shortest possible route of six companies are selected. The route of the pipeline network is shown in Figure 1.

Figure 1: Flaregas pipeline network

The main pipeline starts at PTT Chemical I-1 and ends at PTT LNG Terminal. Along the main route, six intermediate flows connect to the main route. The pipeline named “Con_1” to “Con_6” is the connected pipeline of Thai Polypropylene (TPP), PTT Chemical-I1, HMC Polymer, PTTAR, Siam Polyethylene (SPE), and Bangkok Synthesis (BST) to the main pipeline respectively. The lengths of each pipeline are shown in Table 1.

Table 1 The length of each pipeline in flare gas pipeline network

Routes	Length (km.)	Routes	Length (km.)
Main_1	1.45	Con_2	0.19
Main_2	0.45	Con_3	0.82
Main_3	0.64	Con_4	0.19
Main_4	1.00	Con_5	0.94
Main_5	3.87	Con_6	0.64
Con_1	1.00	Total	11.19

3. SIMULATION RESULTS AND CASE SCENARIO

Sizes of each line in the pipeline network are designed with flare system analyzer. The flare pipeline network is required to have an ability to handle all wastes from 6 industries for both regular and emergency cases.

3.1 Assumption

1. In normal operating cases, the waste gas temperature and pressure, feed into the system are equal to 35 ^{o}C and 1.6 bars respectively.

2. In an emergency case, the waste gas temperature and pressure are 70 ^{o}C and 5.22 bars, respectively.

3.2 Design individual flare system

To design a flare system, there are many criteria needed to be considered [3].

1. Flare pipeline system must have an ability to handle their maximum load design.

2. MABP* must not exceed 60% of set relief valve pressure.

3. Mach No.** must not exceed 0.7 for tailpipe and must not exceed 0.5 for the header.

4. Noise level*** must not exceed 85 dBA.

** The Allowed Back Pressure (MABP) is the pressure that is allowed to exist at the outlet of a pressure relief device as a result of the pressure in the discharge system. It is the sum of the superimposed and built-up back pressure.*

*** Mach No. is the ratio of fluid flow velocity to fluid sonic velocity. For tailpipe, Mach No. commonly limits to 0.7.*

**** Noise levels the noise which generates from fluid flow through Pressure Relief Valve (PRV), tailpipe and header.*

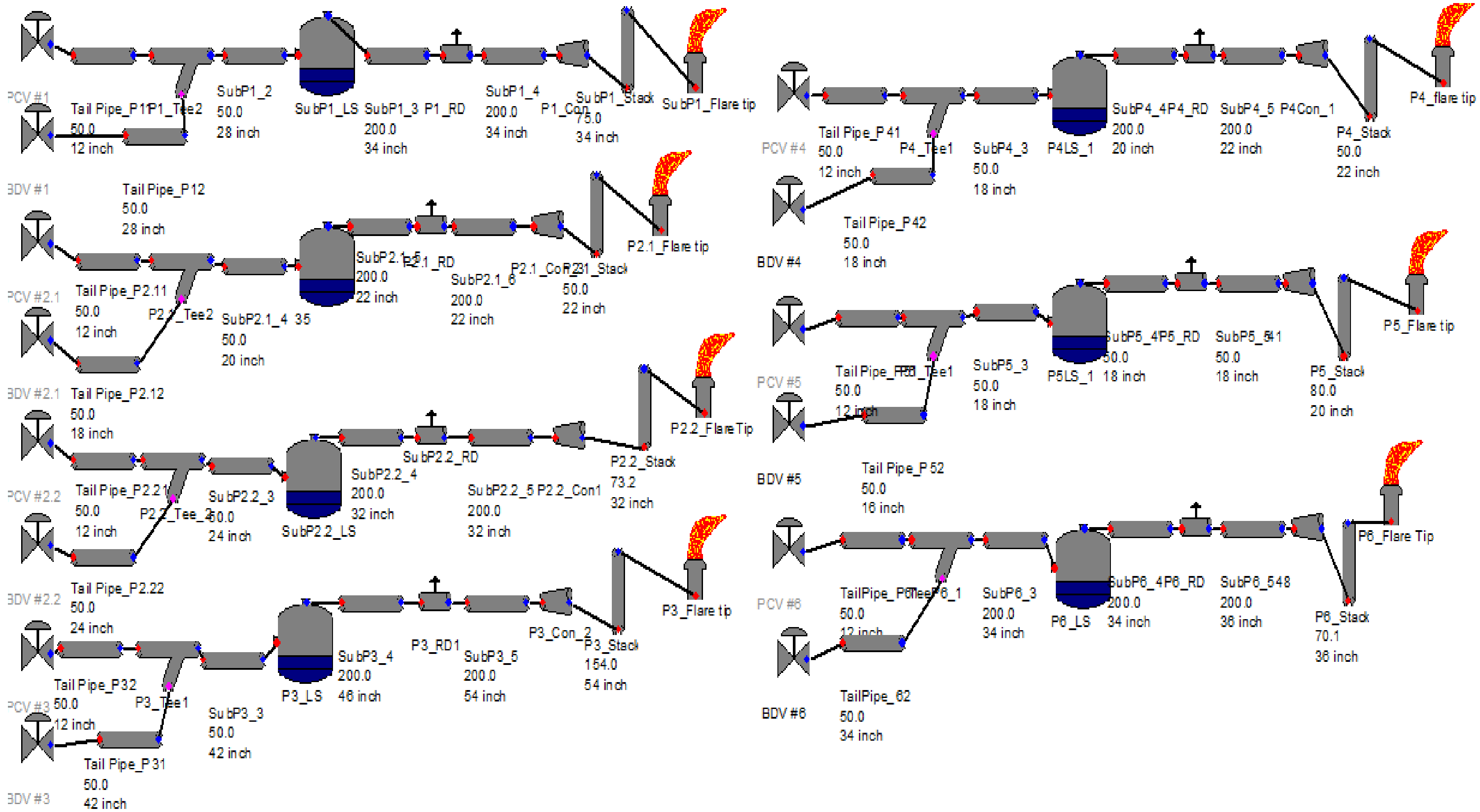

Figure 2: PFD of the individual flare system.

Table 2 Individual flare system simulation result

Company	Maximum design load (kg/hr)	Tail pipe (in)	Sub pipe_1 (in)	Sub pipe_2 (in)	Sub pipe_3 (in)	Stack (in)
TPP Company	404,000	26	30	30	32	34
PTT Chemical- I1	260,000	30	30	34	42	42
HNC stack_1	124,700	16	18	20	20	20
HNC stack_2	216,000	20	22	26	26	26
PTT AR	897,840	32	34	42	46	46
BST Company	115,000	16	16	18	20	20
SEP Company	98,000	14	16	16	16	18

After every flare systems are designed, PFD of the individual flare system and the dimension of each pipe are shown in Figure 2 and Table 2, respectively. The process control valves (PCV) and process blow down valves (BDV); numbers 1 to 5, represent the valves of TPP company, PTT Chemical-I1, HMC stack 1 and 2, PTT AR, BST company and SPE company respectively. From the simulation results, the diameter of the pipe is increasing with the wastes gas flow rate. The smallest diameter of the tailpipe is equal to 14", which handles the maximum of the waste gas flow rate of SEP company, equal to 98,000 (kg/hr). The largest tailpipe is equal to 42", which belongs to the maximum waste gas flow rate of PTTAR. It can be observed that, after tailpipe, sizes of pipe are tented to increase to minimize Mach No. The values of MABP, noise level, and Mach No. of each pipeline are in Table 3.

Table 3 Individual flare system simulation result

Company	Back pressure (bar abs)	Noise level	Mach No.			
			Tail pipe	Sub pipe_1	Sub pipe_2	Sub pipe_3
TPP Company	2.6920	81.9	0.291	0.256	0.316	0.354
PTT Chemical- I1	2.6718	80.9	0.303	0.356	0.325	0.302
HNC stack_1	2.5825	74.0	0.285	0.253	0.224	0.277
HNC stack_2	2.6451	80.4	0.326	0.312	0.248	0.302
PTT AR	2.1648	94.2	0.405	0.434	0.322	0.322
BST Company	2.5580	69.5	0.246	0.275	0.244	0.264
SEP Company	2.6887	74.3	0.291	0.264	0.317	0.366

3.3 Design main transportation pipeline

After the route of the pipeline has been selected, the individual flare system has been designed. The next simulation is to design the main transportation pipeline. The criteria of pipeline sizing are to develop a pipeline network to minimize both the back pressure in the system and the consequence of plant blowdown case.

The PFD of flare pipeline network illustrated in Figure 4. From the PFD, the pipelines named "Main_1" to "Main_6" represent the main pipeline in the pipeline network. Also, the pipelines named "Con_1" to "Con_6" represent the connection pipeline between plant no. 1 to 6 from the main pipeline.

After specified all necessary information, the results are in Table 4. To minimize the effect of plant power failure to the pipeline network, the mass flow rate values into the pipeline network from power failure must be minimum. Therefore, the diameters of the connection pipeline must be lowest. From the simulation results, all of the connection pipeline diameters are 12" except "Con_3" at 32". Hence, this pipeline; "Con_3", needs to handle waste as from HMC Polymer Company both stacks 1 and 2, which make pipeline "Con_3" had a diameter larger than other pipelines. To handle all main pipeline waste gas from 6 plants, the dimension of pipeline "Main_1" to "Main_5" need the sizes of 46", 48", 48", 48" and 60"; respectively.

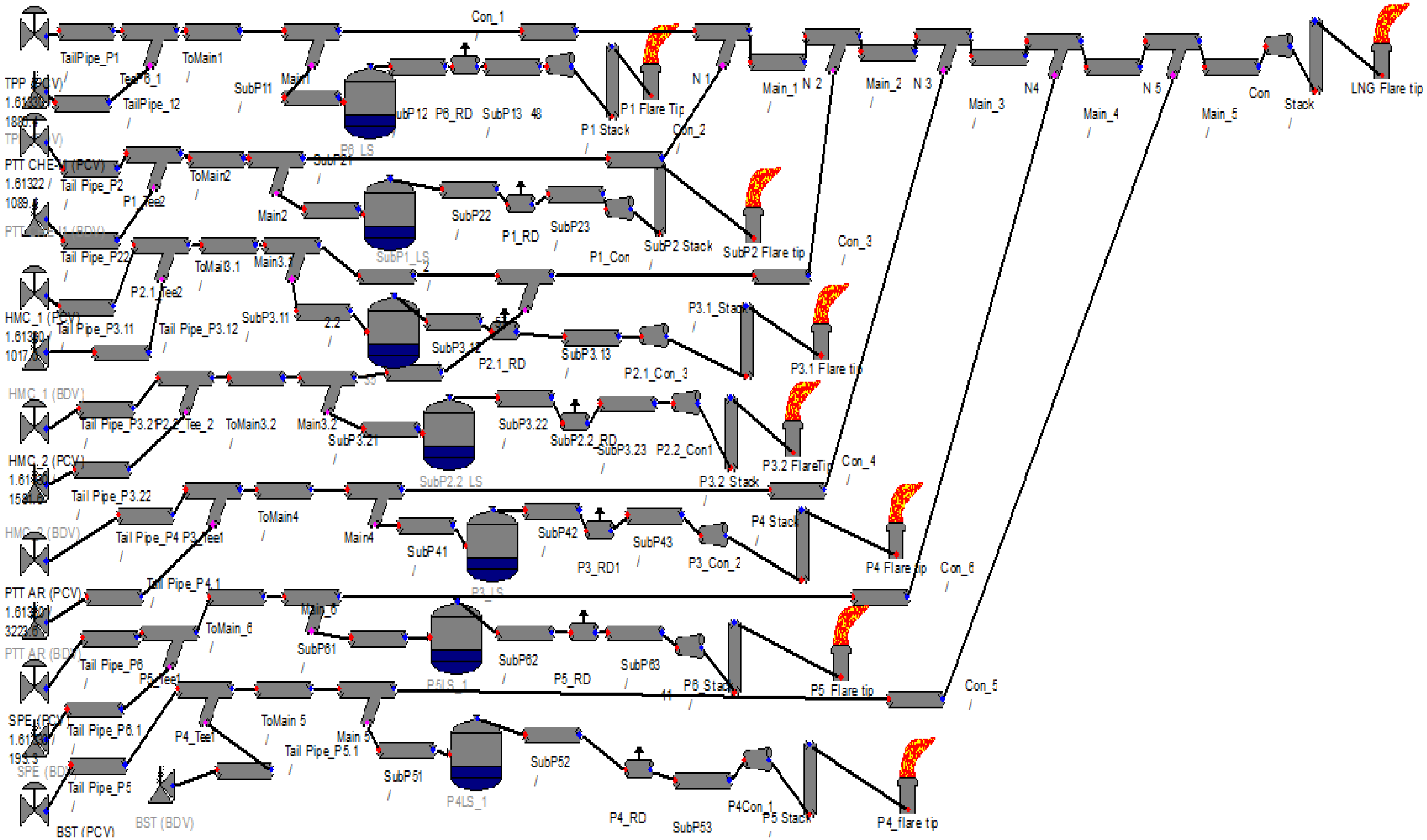

Figure 3: PFD of the flare pipeline network

Table 4 The dimension of each pipeline in the flare pipeline network.

Route	Length (km.)	Pipe diameters (inch)	Route	Length (km.)	Pipe diameters (inch)
Main_1	1.45	46	Con_2	0.19	12
Main_2	0.45	48	Con_3	0.82	32
Main_3	0.64	54	Con_4	0.19	12
Main_4	1.00	54	Con_5	0.94	12
Main_5	3.87	60	Con_6	0.63	12
Con_1	1.00	12	Total	11.19	

In normal operating case, there will be 12.4 tons/hr of waste gas, from six plants, flow into the network. Thosewastegases from each plant may create the back pressure back to PCV, either to itself or to other five plants. The results from the simulation, in normal operation case, are shown in Table 5. The back pressure of all six plants still follows the MABP at 1.253 bara. The highest value of back pressure is 1.0632 bara, from PTT Chemical I-1 company with 4.089 tons/hr of mass flow rate.

Table 5 Flow rate and back pressure of each plant

Company	Flow rate (tons/hr)	Back pressure (bar abs)
TPP Company	1.886	1.029
PTT Chemical- I1	4.089	1.062
HNC stack_1	1.016	1.017
HNC stack_2	1.591	1.019
PTT AR	3.223	1.033
SPE Company	0.193	1.017
BST Company	0.458	1.016
Total	12.456	

3.4 Study and simulation

Scenario 1: One plant shutdown

In this scenario, the assumption is that there is only one plant shutdown at a time. Shutdown plant comes from an emergency or normal plant shutdown situations. From plant shutdown situation, the staging drum of shutdown plant will breakdown because of the pressure is higher than staging drum set pressure. The streams in the process will flow into flare system thought PRV and spread to local flare stack and to flare pipeline network respectively.

The flow rates of each plant shutdown schedule and their back pressure effects from Aspen Flare System Analyzer are in Table 6.

Table 6 Flow rate of each company through the pipeline network and back pressure of scenarios

Scenarios	Indicator	TPP Company	PTT Chemical- I1	HMC plant_1	HMC plant_2	PTT AR	SPE	BST
TPP plant shut down	Flow rate (tons/hr)	160.8	4.089	1.016	1.591	3.223	0.193	0.458
	Back pressure (bar abs)	1.396	1.02	1.019	1.02	1.035	1.017	1.04
PTT Chemical-I1 plant shut down	Flow rate (tons/hr)	1.886	178.4	1.016	1.591	3.223	0.193	0.458
	Back pressure (bar abs)	1.058	2.055	1.034	1.036	1.047	1.028	1.048
HMC polymer 1 plant shut down	Flow rate (tons/hr)	1.886	4.089	106.9	1.591	3.223	0.193	0.458
	Back pressure (bar abs)	1.036	1.031	1.959	1.052	1.045	1.025	1.046

Table 6 (Cont.) The flow rate of each company through the pipeline network and back pressure of scenarios

Scenarios	Indicator	TPP Company	PTT Chemical- I1	HMC plant_1	HMC plant_2	PTT AR	SPE	BST
HMC polymer 2 plant shut down	Flow rate (tons/hr)	1.886	4.089	1.016	124	3.223	0.193	0.458
	Back pressure (bar abs)	1.032	1.027	1.656	1.042	1.035	1.022	1.044
PTT AR plant shut down	Flow rate (tons/hr)	1.886	4.089	1.016	1.591	794.6	0.193	0.458
	Back pressure (bar abs)	1.031	1.026	1.026	1.028	1.526	1.023	1.046
SPE plant shut down	Flow rate (tons/hr)	1.886	4.089	1.016	1.591	3.223	3.693	0.458
	Back pressure (bar abs)	1.021	1.016	1.016	1.017	1.032	1.018	1.038
BST plant shut down	Flow rate (tons/hr)	1.886	4.089	1.016	1.591	3.223	0.193	59.27
	Back pressure (bar abs)	1.021	1.016	1.016	1.018	1.032	1.015	1.08

The results show that, the highest mass flow rate of plant shutdown equal to 794.6 tons/hr; the flow rate of the PTT AR plant. From this case, BST company will face the highest back pressure. Still, the value is within the MABP. In contrast, the lowest amount is at 3.693 tons/hr; the flow rate of the SPE company plant. From the simulation results, back pressures of shutdown plant of all scenarios maintain within MABP limited. Moreover, the back pressures of the other five plants are below staging drum set pressure of each plant, which means that in any case of only one plant shutdown per time will not impact to the other companies in the network.

Scenario 2: Two nearby plant shutdown

In this scenario, the assumption is that there is two nearby plant shutdown from an emergency case. From Figure 1, there are only two plants that have together effect. Those plants are HMC plant 1 and 2. Because of the HMC plants are located nearby each other, an emergency case such as plant fire or plant explosion may have a significant impact on the other.

The value of HMC plant_1 and HMC plant_2 shutdown mass flow rate, and back pressure are in Table 7. The back pressure of HMC plant_1 and HMC plant_2 are equal to 1.971 and 1.616 bars, respectively, which not exceeded MABP. Furthermore, the values of back pressure of the other four plants are also not exceed staging drum set pressure. The result can be concluded that even if HMC plant_1 and HMC plant_2 have an emergency case which needs to relief a total of 240 tons/hr of waste gas into the system, the system still can handle it. The simulation results of this scenario are shown in Table 7.

Table 7 Flow rate and back pressure of each plant when BST company plant shut down

Company	**Flow rate (tons/hr)**	**Back pressure (bar abs)**
TPP Company	1.886	1.055
PTT Chemical- I1	4.089	1.051
HMC plant_1	106.9	1.969
HMC plant_2	123.9	1.611
PTT AR	3.223	1.061
SPE Company	0.193	1.038
BST Company	0.458	1.055

4. FLARE PIPELINE NETWORK MONITORING SYSTEM

Flare network monitoring system is built up to make the pipeline network more natural to access and monitor by the operators. This system allows operators to monitor the necessary information of this pipeline network nearly real-time.

The information, shown in the monitoring system consisted of mass flow rate and pressure at the outlet of PCV of each company, the pressure at the outlet of the connection pipeline and the inlet pressure of the PTT LNG terminal. The window of this system is shown in Figure 4.

File Name : Flare Pipeline Network PCV.fnw

Run Model

Source	Mass Flowrate (kg/hr)	Pressure (bar abs)	Pressure @ Con Pipe (bar abs)	Pressure @ Main Flare (bar abs)
TPP (PCV)	4597	1.0142	1.0141	1.0141
PTT CHE-I1 (PCV)	3724	1.0473	1.0431	
HMC_1 (PCV)	1036	1.0160	1.0158	
HMC_2 (PCV)	1582	1.0174	1.0170	
PTT AR (PCV)	3093	1.0281	1.0263	
SPE (PCV)	198	1.0149	1.0163	
BST (PCV)	472	1.0164	1.0149	

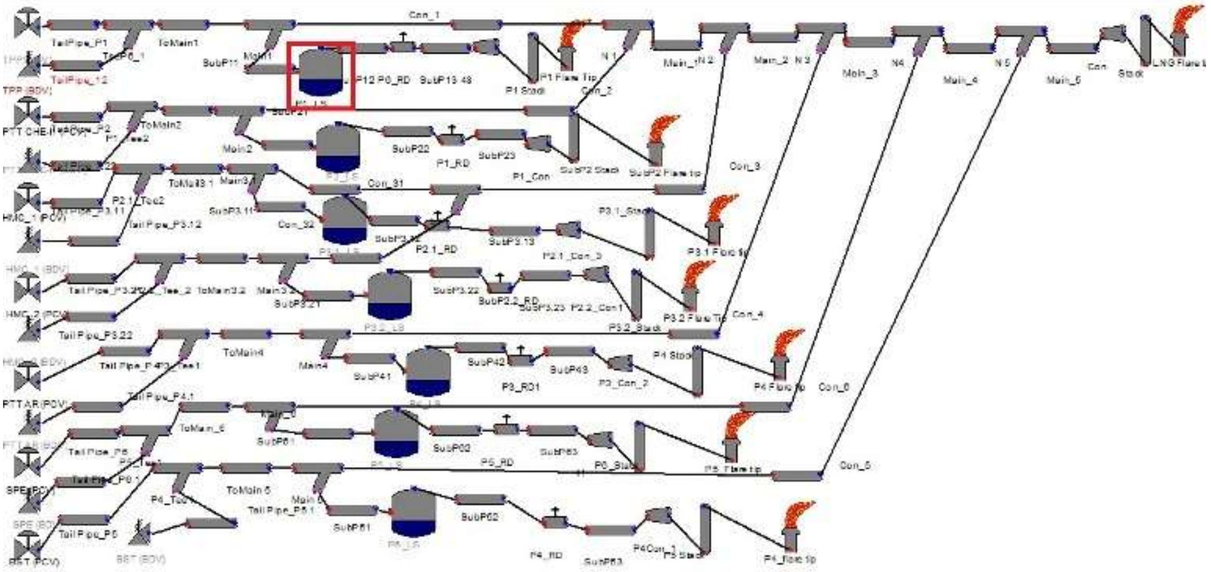

Figure 4: Monitoring system window

From Figure 4, "File Name" represents the Aspen Flare System Analyzer file in the calculation and "Run Model" bottom is used to order this system to run the model. Each column represents the source of waste gas, mass flow rate, the pressure at the PCV, the pressure at the outlet of the connection pipeline, and pressure at the inlet of PTT LNG terminal. The alarms have been set in case of flare system of any plant is operated (staging drum activated) and when the inlet pressure of PTT LNG terminal lower than 0.1 barg or higher than 0.9 barg. The alarm will highlight plant which staging drum is activated and show the location of the plant. The system delay comes from the calculated pressure displayed in the system; it is not real-time values. The information transfer; especially the value of mass flow rate to Aspen Flare System Analyzer, will take approximately 15 sec to calculate and to send the Excel.

5. COST ESTIMATION

The main costs of gas pipeline project mainly come from pipeline materials cost. Pipeline materials cost can be calculated from Equation (1).

$$PMC = 0.0246(D-T)TLC \quad (1)$$

where

PMC = pipe material cost, $

L = length of pipe, km

D = pipe outside diameter, mm

T = pipe wall thickness, mm

C = pipe material cost, $/metric ton

Costs of each pipeline are shown in table 8. From this table, Main_5 has the highest value of pipeline construction cost, which equals to 1.37 Million dollars and consumes more than 50% of total pipeline construction cost. The total pipeline construction cost is equal to 2.42 Million dollars.

Table 8 Pipeline material costs

Route	Length (km)	Diameter (mm)	Thickness (mm)	Cost ($)
Main_1	1.45	1168.4	12.7	295,301.70
Main_2	0.45	1219.2	12.7	95,662.69
Main_3	0.64	1371.6	12.7	153,194.20
Main_4	1.00	1371.6	12.7	239,366.00
Main_5	3.87	1524.0	12.7	1,370,445.00
Con_1	1.00	304.8	12.7	51,890.52
Con_2	0.19	304.8	12.7	9,859.20
Con_3	0.82	812.8	12.7	115,754.9
Con_4	0.19	304.8	12.7	9,859.20
Con_5	0.94	304.8	12.7	48,777.10
Con_6	0.64	304.8	12.7	33,209.83
			SUM	2,423,321

6. CONCLUSION

This project objective is to design flare pipeline network in Map Ta Phut Industrial Estate (MTP IE) to transport wastes from 6 companies to PTT LNG terminal. Group of companies consists of Thai Polypropylene, PTT Chemical I-1, HMC polymer (plants 1 and 2), PTT AR, Siam Poly Ethylene (SPE), and Bangkok Synthetics (BST). The flare pipeline network is designed to operate on the pipe rack in MTP IE to minimize the construction cost. The route of the pipe rack is overviewed through Google Earth, and the flare pipeline network route is selected. The sizes of each pipeline are designed via Aspen Flare System Analyzer. The pipeline monitoring system is developed by a Visual Basic (VB) program. Furthermore, the flare pipeline construction cost is proposed by build-in cost estimator.

From pipeline network design, the total pipeline network length is equal to 11.19 km. The total length of the main pipeline is 7.41 km. The main pipeline diameters are equal to 46" 48" 54" 54" and 60"; respectively. The connection pipelines, which connect each company to the main pipeline, equal to 12" except HMC Polymer. This because HMC polymer connection pipeline needs to handle waste as from two sources, which are HMC polymer stacks 1 and 2. The simulation results show that the designed pipeline network can handle all scenarios both in normal operation case and in emergency case. This can be proved from the back pressure of each plant of all scenarios are within MABP limit, and staging drum set pressure limit. According to cost estimation, the total project construction cost is equal to 8.38 million dollars.

7. ACKNOWLEDGMENT

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8. REFERENCES

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9. APPENDIX A

Table A.1 Flare system information of TPP Company in normal operation case and emergency case

Flare system	Normal case	Emergency case
Stack height (m)	80	
Tip diameter (m)	0.46	
Mass flow rate (kg/hr)	1,886.35	160,815
Composition	Mass frac.	Mass frac.
Methane	0.490	
Propane	0.037	1
Propene	0.166	
Hexane	0.095	
Nitrogen	0.213	

Table A.2 Flare system information of PTT Chemical-I1 in normal operation case and emergency case

Flare system	Normal case	Emergency case
Stack height (m)	75	
Tip diameter (m)	0.80	
Mass flow rate (kg/hr)	4089	178,458
Gas composition	Mass Frac.	Mass Frac.
Butene	0.011	0.014
Ethylene	0.148	0.191
Hexane	0.012	0.015
Hydrogen	0.126	0.162
Nitrogen	0.476	0.613
Methane	0.227	0.005

Table A.3 Flare system information of HMC Polymer in typical operation case and emergency case

Flare system	Plant 1		Plant 2	
	Normal case	Emergency case	Normal case	Emergency case
Stack height (m)	50		73	
Tip diameter (m)	0.6		0.75	
Mass flow rate (kg/hr)	1016	106,531	1591	123,185
Gas composition	Mass Frac.	Mass Frac.	Mass Frac.	Mass Frac.
Propene	0.121	0.797	0.075	0.147
Propane	0.448	0.198	0.225	0.44
Ethylene	0.003	0.005	0.208	0.407
Methane	0.388	0.006	0.491	0.006

Table A.4 Flare system information of PTT AR in normal operation case and emergency case

Flare system	Normal case	Emergency case
Stack height (m)	154	
Tip diameter (m)	1.37	
Mass flow rate (kg/hr)	3223.56	794,611
Gas composition	Mass Frac.	Mass Frac.
Methane	1	0.004
Propane		0.007
I-Butane		0.030
N-Butane		0.059
I-Pentane		0.078
N-Pentane		0.069
Cyclopentane		0.039
Hexane		0.154
Methylcyclopentane		0.042

Table A.4 (Cont.) Flare system information of PTT AR in normal operation case and emergency case

Flare system	Normal case	Emergency case
Cyclohexane		0.080
Benzene		0.040
Heptane		0.108
Ethylcyclopentane		0.005
Toluene		0.084
Octane		0.087
Methylcyclohexane		0.106
Ethylbenzene		0.009

Table A.5 Flare system information of SPE Company in normal operation case and emergency case

Flare system	Normal case	Emergency case
Stack height (m)	80	
Tip diameter (m)	0.457	
Mass flow rate (kg/hr)	193.3	
Gas density (kg/m3)	1.42	
Composition	Mass frac.	Mass frac.
Methane	1	0.052
Carbon dioxide		0.801
Carbon monoxide		0.136
Nitrogen dioxide		0.004
Ethylene		0.002
Butene		0.002
Octene		0.002
Hydrogen		0.002

Table A.6 Flare system information of BST Company in normal operation case and emergency case

Flare system	Information	Flare system
Stack height (m)	50	
Tip diameter (m)	0.6	
Mass flow rate (kg/hr)	458	59,275
Gas composition	Mass frac.	Mass frac.
Methane	0.775	0.006
Propane	0.062	0.252
Propadiene	0.005	0.02
Isobutane	0.083	0.338
n-butane	0.018	0.075
Tran-2-Butene	0.001	0.002
Butene-1	0.009	0.038
Isobutene	0.007	0.028
Cis-2-Butene	0	0.001
1,3Butadiene	0	0.001
3-Methyl-1-Butene	0	0.002
Dimetyl Ether	0.059	0.239