Design of a Fuel Gas Treatment and Distribution System

ADVANCING CHEMICAL ENGINEERING WORLDWIDE

CONTENTS **PAGE**

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ABBREVIATIONS

BDV	Blowdown Valve
DP	Design Pressure
EOS	Equation of State
HTC	Heat Transfer Coefficient
ID	Inside Diameter
LFL	Lower Flammability Limits
LHV	Lower Heating Value
NB	Nominal Bore
OD	Outside Diameter
OP	Operating Point
PCV	Pressure Control Valve
PFD	Process Flow Diagram
PID	Proportional, Integral, Derivative Controllers
PSV	Pressure Safety Valve
SP	Set Point
SRK	Soave-Redlich-Kwong
TCV	Temperature Control Valve
UFL	Upper Flammability Limits

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1. INTRODUCTION

This report presents the design of a fuel gas processing and distribution system for an onshore oil pumping facility operated by XXX Petroleum Co.

The pumping station will be designed for a throughput of 60,000bbls of oil per day and includes processing units such as; storage tanks for oil and water, pumps, water bath heaters, metering skid and other utilities and services such as power generation, plant and instrument air, industrial water systems and drain systems.

Fuel gas is the primary fuel source for power generation and the water bath heaters and is imported by pipeline from a nearby facility.

2. SCOPE OF WORK AND BASE DATA

2.1 Scope of Work

The fuel gas will be required to be treated to ensure that the fuel gas specification requirements advised by the heater and generator vendors is met, such that no power loss occurs due to fuel gas quality. The system in designed for 2.5MMscfd gas.

The scope of work is to design the fuel gas treatment and distribution for the pumping station. This includes review of fuel gas heater and scrubber, heat/material balance, line sizing and associated instruments, etc.

2.2 Process Description

A process flow diagram of the fuel gas system is given in Appendix A1. The incoming fuel gas will be heated to 45^{o}C in a heating coil in a water bath heater to prevent hydrate formation before pressure reduction to the required distribution pressure.

After pressure reduction, water/hydrocarbon condensates are removed in a scrubber before the gas is heated to about 15^{o}C by a second heating coil in the same heater, prior to distribution. Separated liquids from the scrubber will flow via level control to the produced water tank.

The water bath heater will be dual-fired by fuel gas. Diesel will be used for black-start, when fuel gas is not available.

2.3 Base Data

The base data for the fuel gas system is summarised below.

2.3.1 Temperatures and Pressures

- Fuel gas system design pressure (inlet system) 142 barg
- Fuel gas system design pressure (distribution) 6.9 barg
- Fuel gas system design temperature (inlet) 80 ^{o}C
- Fuel gas system design temperature (distribution) 100 ^{o}C
- Normal operating pressure (inlet system) 100 barg
- Normal operating pressure (distribution) 5.7 barg
- Minimum fuel gas temperature to users 10 ^{o}C
- Maximum fuel gas temperature to users 50 ^{o}C

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2.3.2 Fuel Gas Composition and Fluid Properties

The fuel gas is expected to be supplied to the users at 100barg and at 25°C with the following composition listed in Table 1.

Table 1: Fuel Gas Composition

Component	Mol %	Mass %
N2	0.37	0.55
CO2	1.06	2.46
C1	89.64	75.84
C2	3.52	5.58
C3	2.77	6.44
i-C4	0.68	2.08
n-C4	1.24	3.80
i-C5	0.42	1.60
n-C5	0.07	0.27
C6+	0.23	1.39
Total	100.00	100.00

Table 2: Fuel Gas Properties

Property	Unit	@ 0.7°C & 5.7barg	@ 25°C & 100barg
Vapor fraction	-	0.997	1.00
Mass density	kg/m3	5.75	97.22
Molecular weight	-	18.96	
HHV	MMBtu/gal	15230	
LHV	MMBtu/gal	13770	
Hydrate formation temp	°C	-4.7	20.78
HC dewpoint	°C	20.59	22.98
Water dewpoint	°C	-8.4	24.6
Cp/Cv	-	1.30	1.79

3. TECHNICAL ASSESSMENT

3.1 Project Constraints

The client has provided existing facilities for use for the fuel gas system distribution. These are:

- 150lb rated fuel gas Scrubber 1.219m (ID) x 2.438m (H).
- 900lb rated fuel gas Indirect (Water Bath) Heater with 2 sets of heating coils (2” and 4” respectively). Water at 93^{o}C is the heating medium.

The supplied equipment/instruments are constraints in the process design and the system will be modified to optimally utilize them. The system design capacity is 2.5MMscfd.

3.2 Project Approach

The following approach has been used to assess the fuel gas system requirements and develop an optimal design.

1. Determine gas consumption of each user.
2. Determine overall fuel gas rate required - up to 2.5MMscfd gas available.
3. Perform fuel gas system simulation to obtain heat and material balance for system.
4. Capacity review of the heater - water bath heater with the process fluid heated up within coils.
5. Capacity review of the scrubber - 150lb rated to be capable of handling 2.5mmscfd of gas.
6. Review the process control - i.e. the scrubber pressure control and the heater temperature control.
7. Review the equipment process safeguards - pressure safety valves and blowdown valve.
8. Size associated lines in fuel gas system.

4. DESIGN AND CALCULATIONS SUMMARY

4.1 Assessment of Fuel Gas Demand

The fuel gas consumers are as follows: 2 x Inlet Heaters; 6 x Export Heaters; 1 x Fuel Gas Heater; 3 x Gas Generators. There are also 2 Bi-Fuel Generators which use diesel and can also use gas. The fuel gas flowrate required per consumer is obtained as follows:

Heaters:

$$FG\ (mmscfd) = \left[(Heater\ Duty\ (mmbtu/hr) \div LHV\ (btu/sm^3)\right] \qquad \textbf{Eqn 4-1}$$

Where,
Duty = 6.30, 5.67 and 1.0MMBtu/hr (for inlet, export and fuel gas heaters)
Efficiency = 69%

Generators:

$$FG\ (mmscfd) = \left[(Gen.\,Duty\ (mmbtu/hr) \div LHV\ (btu/sm^3)\right] \qquad \textbf{Eqn 4-2}$$

and generator duty:

$$Gen.\,Duty(mmbtu/hr) = \left[(Output\ (kW) \times FuelConsumption \times 10^{-6}\ (btu/kW.hr)\right] \qquad \textbf{Eqn 4-3}$$

Where,
Output = 0.975 and 1.20kW (for the gas generator and bi-generator respectively)
Fuel consumption = 10,720 Btu/kW-hr
Efficiency = 95%

The bi-fuel generator runs primarily on diesel and is used for start-up and as backup generator. It can also run on fuel gas.

Table 3: Flowrate for the individual heaters

Heaters	Heater Duty (MMBtu//hr)	Heater Duty (MMBtu//hr) @69% LHV Eff.	FG LHV (Btu/sm^3)	FG Flowrate (sm^3/hr)	FG Flowrate mmscfd	% of Total
1	6.30	9.13	36214.67	252.12	0.21	17.92
2	6.30	9.13	36214.67	252.12	0.21	
					0.43	
3	5.67	8.22	36214.67	226.91	0.19	48.37
4	5.67	8.22	36214.67	226.91	0.19	
5	5.67	8.22	36214.67	226.91	0.19	
6	5.67	8.22	36214.67	226.91	0.19	
7	5.67	8.22	36214.67	226.91	0.19	
8	5.67	8.22	36214.67	226.91	0.19	
					1.15	
9	1.00	1.45	36214.67	40.02	0.03	1.42
			Total	1905.71	1.62	

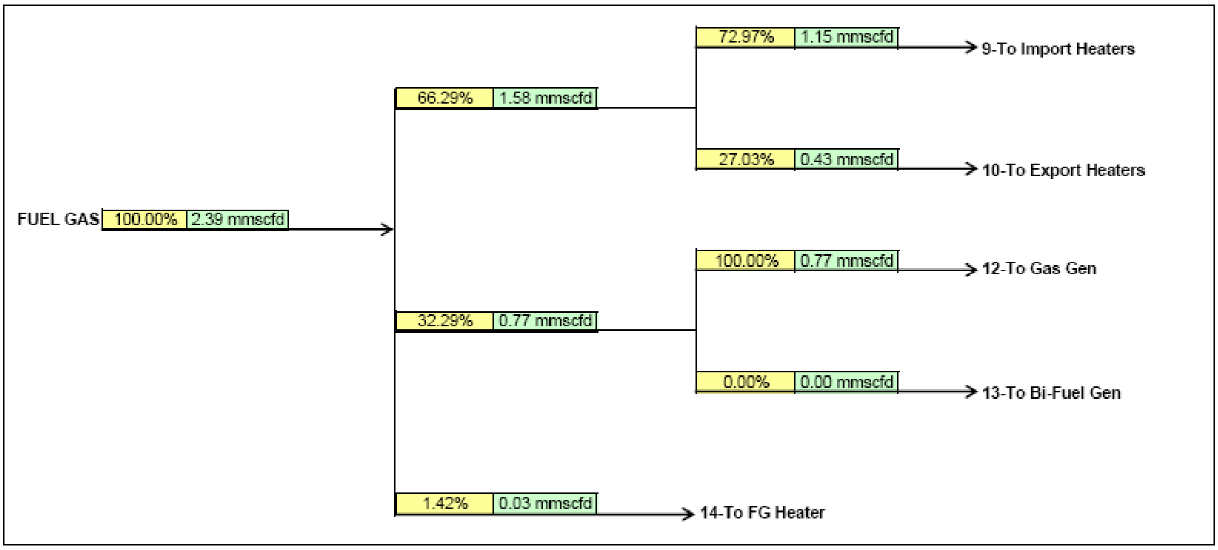
Table 4: Flowrate for the individual generators

Gas Gen	Output (MW)	Eff. (%)	Heating Value (BTU/kg)	Heat Rate (BTU/kW-hr)	FG (kg/hr)	FG (sm3/hr)	FG Flow (mmscfd)	FG Design (mmscfd)	% of Total
1	0.975	95%	45,153	10,720	244	302.95	0.2568	0.2568	32.29
						3	=generators	**0.7703**	

Table 5: Balance Summary

Consumer	Unit Rate (mmscfd)	No of Units	Total (mmscfd)	Prorated to 2.5mmscfd	Ratio (%)
Inlet Heaters	0.21	2	0.43	0.45	17.92
Export Heaters	0.19	6	1.15	1.21	48.37
FG Heater	0.03	1	0.03	0.04	1.42
Gas Gen.	0.26	3	0.77	0.81	32.29
			2.39	2.50	100.00

Figure 1: Summary

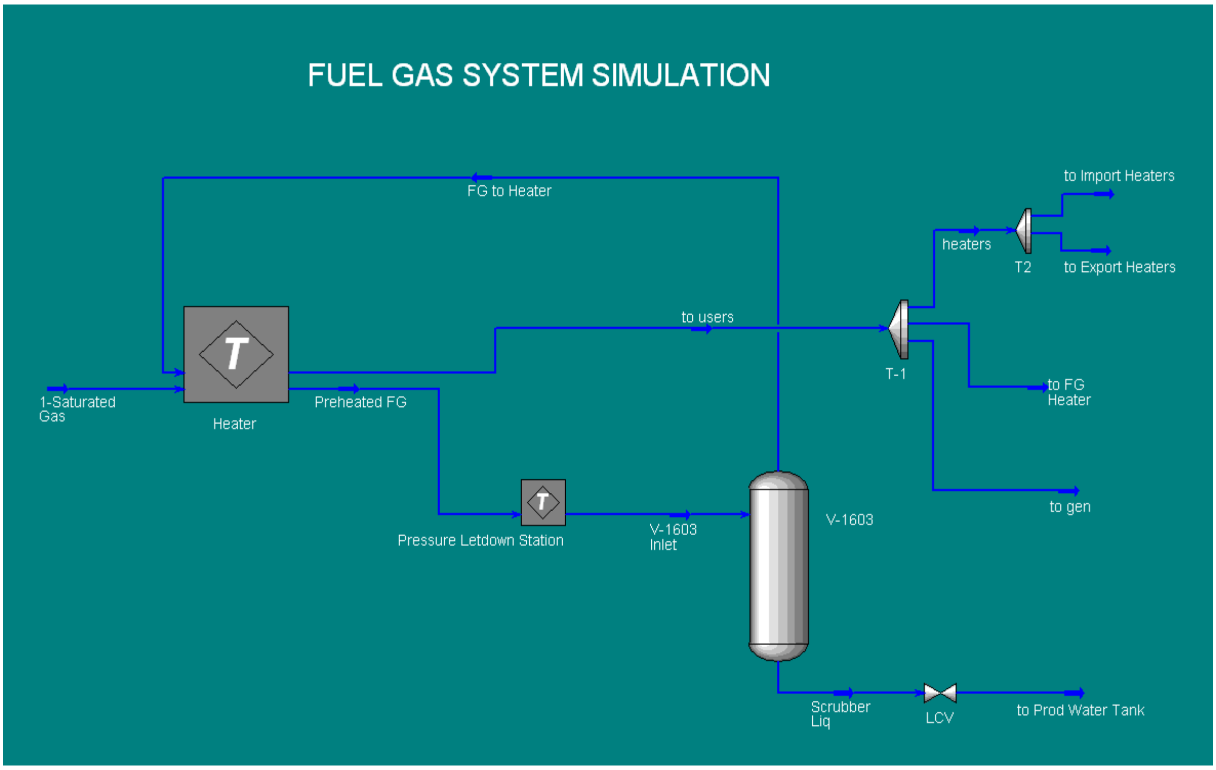


4.2 Fuel Gas Simulation

The process was simulated using Aspen HYSYS to obtain the heat and material balance. The SRK property package was selected.

The Heat and Material is given in Appendix A2.

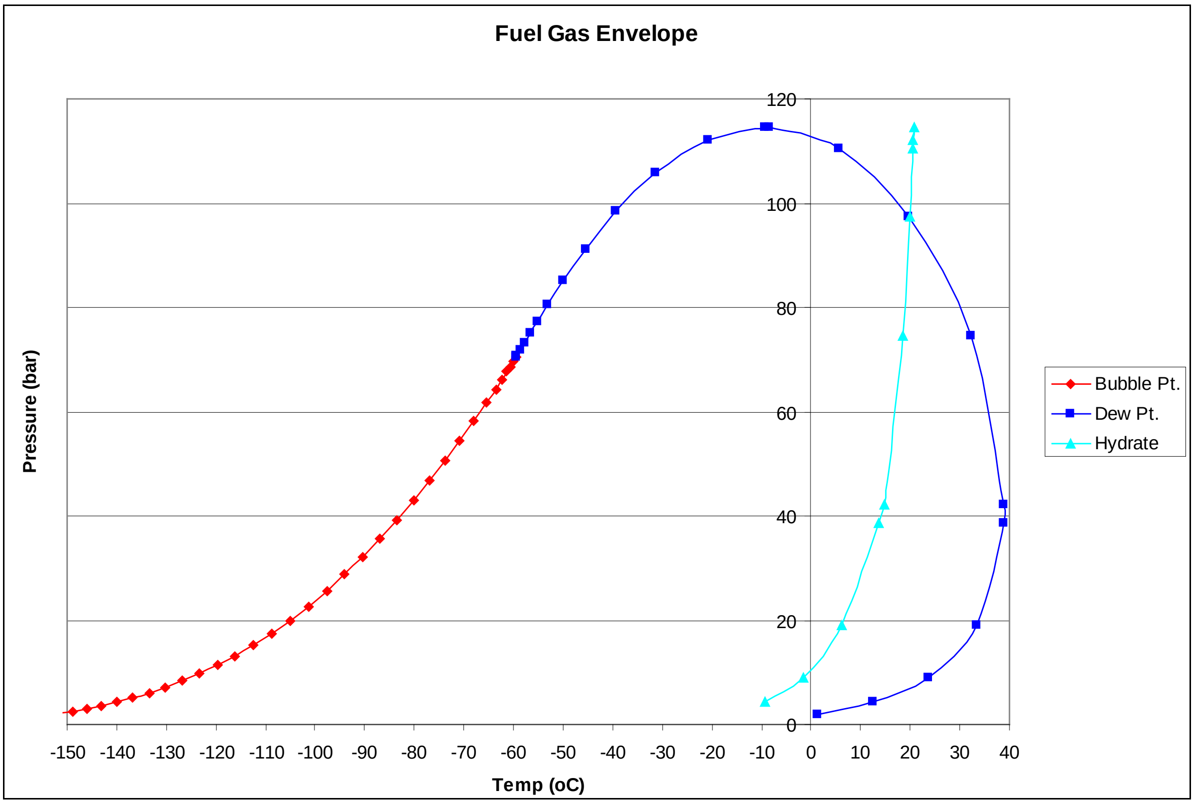
Figure 2: Aspen HYSYS Simulation PFD



4.2.1 Phase Envelope

The fuel gas composition has been used to generate a phase envelope in order to determine the dewpoint conditions at the supply pressure of 5.5barg.

Figure 3: Hydrocarbon Envelope for Composition



The envelope indicates that at a fuel gas supply pressure of 5.5barg the dew point for the fluid is about 15°C. This is the minimum temperature the fuel gas is to be heated to by the water bath heater. The fuel gas scrubber is installed before the heater to knock out any liquids resulting from the pressure drop thus increasing the gas dew point.

4.3 Fuel Gas Heater Review

The heat and transport properties of the heater are obtained via simulation using the heater characteristics from vendor data (Ref 1, Table 6).

Table 6: Data for Heaters

	Inlet Heaters (2x100%)	Export Heaters (6x100%)	Fuel Gas Heater	
Duty (MMBtu/hr)	6.30	5.67	1.0	
Efficiency (%)	69	69	69	
Coil N.D (in)	4	4	2	4
Spec.	A-106B	A-106B	A-106B	A-106B
Schedule	40	40	160	160
Heating Surface (ft^2)	1431	2456	-	-
Coil Length (ft)	-	-	18	18
Overall HTC (Btu/hr-ft^2-F	40	40	29	29

The fuel gas heater has two coils; the first for preheating the import gas and the second one for heating the gas prior to distribution. A TCV is situated on the outlet of the second coil. The heater is a water bath type with heating coils immersed in water at 93^{o}C.

The gas is preheated to compensate for any heat loss from the pressure letdown. A reduction in the inlet pressure from 100barg to 5.7barg results in the temperature falling from 25^{o}C to -26.11^{o}C.

The target for the heater is to preheat the fuel gas to 45^{o}C in the first coil thus compensating for the heat loss across the control valves. The hydrate formation temperature for the gas is -5^{o}C.

The results of the simulation show that when the heater preheats the fuel gas to approximately 45^{o}C the temperature across the control valves drops to 0.7 ^{o}C. Thus the water bath heater is adequate for the process requirement.

The heating effect of the second coil is limited to about 15^{o}C by the use of a three-way TCV supplied with the heater.

4.4 Fuel Gas Scrubber Review

Table 7 gives the design details of the client supplied scrubber.

Table 7: Fuel Gas Scrubber

Diameter, ID (m)	1.219
Length, s/s (m)	2.438
Surface Area (m^2)	19.0
Volume (m^3)	3.32
Operating Pressure (psig)	83.0
Design Pressure (psig)	100.0
Operating Temperature (^{o}C)	0.7
Design Temperature (F)	212 max / -20MMDT
Wall Thickness (in)	0.375
Corrosion Allowance (in)	0.125
Service	Sweet Service, (Oil, Gas, Water, Wax)
Insulation	2” Fiberglass with 0.020” aluminum clad

Calculations (Appendix B1) show that the size of scrubber required for 2.5MMscfd fuel gas is 0.6m (ID) x 2.15m (H). The scrubber is also provided with a pressure safety valve and a blowdown valve which are adequately sized. Thus the supplied scrubber is adequate for the project requirements.

4.5 Process Control

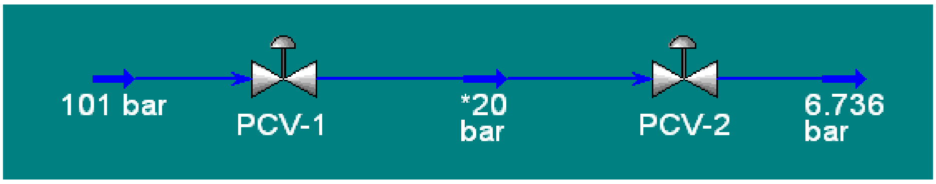
The letdown station consists of two pressure control valves in series. Refer to Fuel Gas System PFD (Appendix A1). The detailed sizing for the control valves are in Appendix B. The outlet temperature of the second PCV is 0.7^{o}C. This is within acceptable limits of the fluids hydrate formation temperature of -4.7^{o}C.

Table 8: Summary of Results

	PCV-1	PCV-2
C_v, valve flow coefficient	1.51	8.33
Valve Type	Globe	Globe
Valve Body Size (inch) *	1	1

* Size subject to vendor review

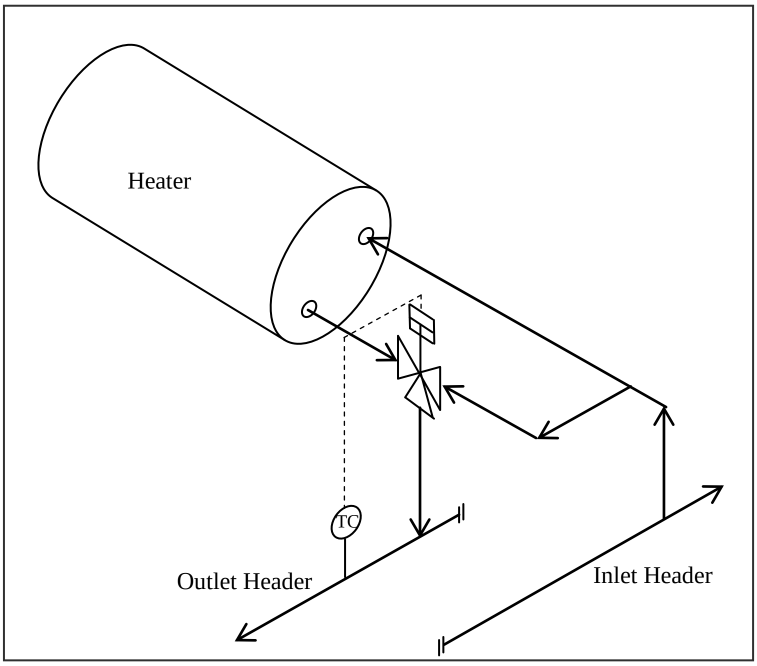
Figure 4: Pressure Letdown Station



Two control valves in series are required to reduce the import pressure of 100barg to 5.7barg based on the sizing criteria for control valves and because of the large pressure differential required.

Apart from the pressure letdown station the outlet of the fuel gas coil is controlled to a minimum of 15°C by a three-way TCV. The first coil inlet is uncontrolled. Both of the controls are traditional feed forward PID controllers.

Figure 5: Temperature Control Valve



4.6 Process Safeguarding

4.6.1 Depressurization

All process equipment operating above 7barg or containing at least $4m^3$ of butane or a more volatile liquid under normal operating conditions shall need to be provided with remotely operated vapour depressurisation valves (Ref. 4).

The BDV is also actuated automatically by a signal from the emergency shutdown system, initiated by fire or gas detection. A restriction orifice is usually used in conjunction with a BDV to restrict flow.

The Scrubber is operated at 83 psig (5.7barg) and the pressure of the inlet stream is controlled by two pressure control valves in series.

Under emergency conditions the fuel gas system (i.e., fuel gas inlet line, heater, PCVs and scrubber) can be isolated. The fuel gas scrubber is blown down to atmosphere via a 2" ball valve (Ref. 13).

The scrubber operates at pressures below 7barg and would not ordinarily require depressurization; however the blowdown of the vessel via the provided valve is examined.

The BDV and vent sizing has been based on the total inventory as a worst case. This is estimated to be $40Sm^3$ of gas (See Appendix C). Depressurisation calculations have been carried out for the design as it is and also with the use of a restriction orifice.

Aspen HYSYS is used to determine the maximum vent rate obtainable and minimum temperatures. The requirement is to blowdown this inventory to 2.86barg (50% of the operating pressure of 5.7barg) within 15mins. The depressurisation profiles are attached in Appendix C.

The minimum temperature obtained is -9.4°C. The piping specification for ASME Class 150 (carbon steel) pipework has a minimum operating temperature of -29°C (Ref. 8). Thus carbon steel piping will be adequate for depressurisation requirements.

4.6.2 Dispersion

Dispersion modelling has been carried out for the vented gases using PHAST. The vented gases comprise a mixture of hydrocarbons which can form a potentially flammable mixture when mixed with air, i.e., between 5% and 15% methane in air; the lower and upper flammability limits (LFL and UFL). The dispersion calculation determines the location of the vent.

PHAST is third-party consequence modelling software used to analyse hazards resulting from leaks and emissions of fluids.

PHAST is used to determine the hazardous area around the vent, i.e., the horizontal and vertical distance from the vent to the edge of the LFL gas cloud (Ref. 12). The scenarios for gas dispersion are given in Table 9.

Table 9: Relief/Blowdown Scenarios – Fuel Gas System

Case	Scenario	Flowrate (kg/s)	Pressure(barg)	Temp. °C)
A1	Fuel Gas Scrubber fire case	0.341	8.34	107
A2	Fuel Gas Scrubber closed outlet	0.658	7.58	76.2
A3	Fuel Gas Scrubber control valve failure	0.636	5.73	0.7
A4	Fuel Gas Scrubber blowdown - without relief orifice	2.466	5.73	0.7
A5	Fuel Gas Scrubber blowdown - with relief orifice	0.026	5.73	0.7

Case A4 is the worst case scenario. Modelling was carried out under the worst case weather conditions obtainable on site with the following results:

Table 10: Fuel Gas Venting Dispersion Distances from Vent Outlet (Case A4)

Horizontal distance to dispersion (m)		Vertical distance to dispersion (m)	
100% LFL	50% LFL	100% LFL	50% LFL
1.77	4.66	+9.74	+13.37
1.82	4.49	+10.81	+15.17
2.41	6.11	+5.42	+7.29
2.94	7.07	+3.47	+4.56

Graphical output from the dispersion calculations are shown in Appendix C.

4.6.3 Radiation: Fuel Gas Vent

During venting there is a possibility that the vented gases could ignite with resultant damage to personnel/equipment from radiation.

Ref. 4 specifies the allowable radiation levels as a function of time. Solar radiation of 0.9kW/m² is assumed for the location.

Table 11: Recommended Design Total Radiation

Permissible design level	Conditions
1.58 kW/m² (500 Btu/h ft²)	Location where personnel with appropriate clothing may be continuously exposed
4.73 kW/m² (1500 Btu/h ft²)	Areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing
6.31 kW/m² (2000 Btu/h ft²)	Areas where emergency actions lasting up to one minute may be required by personnel without shielding but with appropriate clothing
9.46 kW/m² (3000 Btu/h ft²)	Value at design flare release at any location to which people have access; exposure should be limited to a few seconds, sufficient for escape
15.77 kW/m² (5000 Btu/h ft²)	Structures/areas where operators are not likely to be performing duties and where shelter from radiant heat is available

The radiation levels from an ignited vent were modelled using FLARESIM - a third-party software used for the design and rating of flare stacks.

The height of the vent will be determined based on the radiation level measured at grade being below 4.73kW/m² in order to protect personnel. Case A4 is used as basis and the vent is a simple 4" NB unimpeded pipe work vent stack venting to atmosphere.

Appendix C contains the radiation contour plots for Case A4. It was determined that a 10.25m high vent would be required. The 4.73 kW/m², 6.31 kW/m² and 15.7 kW/m² radiation contours would sit at their lowest point at approximately 0m, 3m and 7.5 m above grade, respectively. The flame length was estimated to be approximately 23.65 m. The horizontal distances (i.e. the radii) to radiation levels of 4.73kW/m² and 6.3kW/m² were estimated to be approximately 17.1m and 10.2 m (at "head" height).

The distances to these radiation contours may affect personnel on location and thus the vent height may need to be increased. The rate of "decay" of the radiation was also investigated with the following results.

Table 12: Radiation Decay (Case A4)

Time (sec)	Mass Flow (kg/s)	Volume Flow (m3/s)	Distance(m)		
			4.7 kW/m²	6.3 kW/m²	9.46 kW/m²
0	2.466	1.921	16.8	9.7	-
5	1.711	1.497	13.4	-	-
10	1.202	1.168	9.75	-	-
15	0.805	0.9353	-	-	-
20	0.605	0.7536	-	-	-

Notes: The distances are the horizontal radii from the centre of the vent stack at head height (2 m above grade).

Table 12 shows that despite the fact that the initial distance to radiation level of 4.7kW/m² and 6.3kW/m² are high, this configuration of the vent stack may still be acceptable because the intensity of the radiation decreases rapidly. The radiation intensity around the vent stack decreases to within acceptable levels within 20 seconds because the vented flow is unrestricted.

Radiation modelling was also carried out for Case A2, Fuel Gas Scrubber closed outlet. It was determined that the 4.73 kW/m², 6.31 kW/m² and 15.7 kW/m² radiation contours would sit at their lowest point at approximately 2.2 m, 3.5 m and 9 m above grade, respectively. The flame length was estimated to be approximately 12.6 m. This result was for the same vent stack of 10.5 m. On further investigation if the stack height were to be reduced to 9m, the 4.73 kW/m², 6.31 kW/m² and 15.7 kW/m² radiation contours would sit at their lowest point at approximately 1.4 m, 3 m and 6.3 m above grade, respectively.

However, the Case A2 vent radiation scenario is only applicable if the relief/vent piping is modified to include a restriction orifice downstream the blowdown valve thus restricting its flow.

4.6.4 Over-Pressure Protection

In addition to the blowdown system there is a PSV on both the Fuel Gas Scrubber inlet line and the scrubber itself, both are set at 100psig.

The over-pressure relief devices (PSVs) protecting the fuel gas system have been sized in accordance with API RP 520 (Ref. 5) and API RP 521 (Ref.4) for the most severe individual relief condition. Table 13 identifies the applicable relief conditions considered for the sizing of the PSVs.

Table 13: PSV Relief Conditions

Case
1. Closed / blocked outlet
2. Control valve malfunction
3. Excess heat input/vapour generation
4. External fire

The relief valve has been selected in accordance with API Standard 526 (Ref. 6).

The operating pressure of the scrubber is 83psig (5.7bar). The PSVs are 3” x 4” and calculations are carried out to determine the suitability of these safety valves for the process. The minimum size of PSV required is 1.5” x 3” thus the pre-installed PSVs are adequate. See Appendix B3 for detailed calculations.

4.7 Line Sizing

The sizing of lines for the project was done as per company practice and principles which were based on engineering standards (Ref 8 and Ref 9). The equations and correlations used are as follows:

Line velocities are estimated using: $Q = \frac{v\pi d^2}{4}$ **Eqn 4-4**

Where:
Q = Flowrate (m^3/s)
V = velocity (m/s)
D = inside pipe diameter (mm)

The pressure drop for liquid or gas lines are calculated using the Darcy formula:

$$\Delta P_{100m} = \frac{w^2}{\rho}\left(\frac{62530\,f}{d^5}\right) \qquad \textbf{Eqn 4-5}$$

Where:
$\Delta P100m$ = Pressure drop (kPa/100m)
W = Mass flow (kg/hr)
ρ = Density (kg/m^3)
f = Moody friction factor
d = internal diameter

The Moody friction factor is a function of the Reynolds number and the surface roughness of the pipe. The Moody diagram (Ref. 8) may be used to determine the friction factor once the Reynolds number is known:

$$\mathrm{Re} = \frac{\rho d v}{\mu} \qquad \textbf{Eqn 4-6}$$

Where:
Re = Reynolds number
ρ = Density (kg/m^3)
v = Velocity (m/s)
d = internal diameter (mm)
μ = Viscosity (cP)

Finally, erosional velocities are calculated as per Ref. 7: $V_e = \frac{C}{\rho_m^{0.5}}$ **Eqn 4-7**

Where:
V_e = Erosional velocity (ft/s)
C = Constant (100 for continuous flow)
ρ_m = Gas/Liquid density (lb/ft^3)

The inlet line to the fuel gas system is 4", ASME CL 900. From calculations this size is adequate. The inter-connecting lines within the process are also 4" (and ASME CL 150) and the distribution lines are 2" ASME CL 150 lines. The line sizing and calculations are given in Appendix B4.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Fuel gas demand is expected to be 2.39MMscfd, which is within the design rate of 2.5MMscfd.

2. The supplied scrubber is adequate for project requirements.

3. The supplied heater is adequate for project requirements.

4. The minimum temperature on blowdown is -9.4^{o}C which does not exceed the ASME CL 150 piping specification.

5. Dispersion - the 50% LFL from the Fuel Gas Vent was estimated to be 7m horizontally. This is not expected to pose a hazard to personnel or equipment so long as the fuel gas vent is higher than any equipment within 7m of the vent.

6. Radiation - A Fuel Gas Vent of 10.25m high will expose personnel and equipment to radiation levels of not more than 4.73kW/m^2. This radiation level has a radius of approximately 17.1 m and will last for less than 20 seconds.

5.2 Recommendations

1. A minimum Fuel Gas Vent height of 10.25m above grade is recommended.

2. Modifying the vent piping downstream of the BDV to include a restriction orifice will mean that the vent height can be reduced to 9 m.

6. REFERENCES

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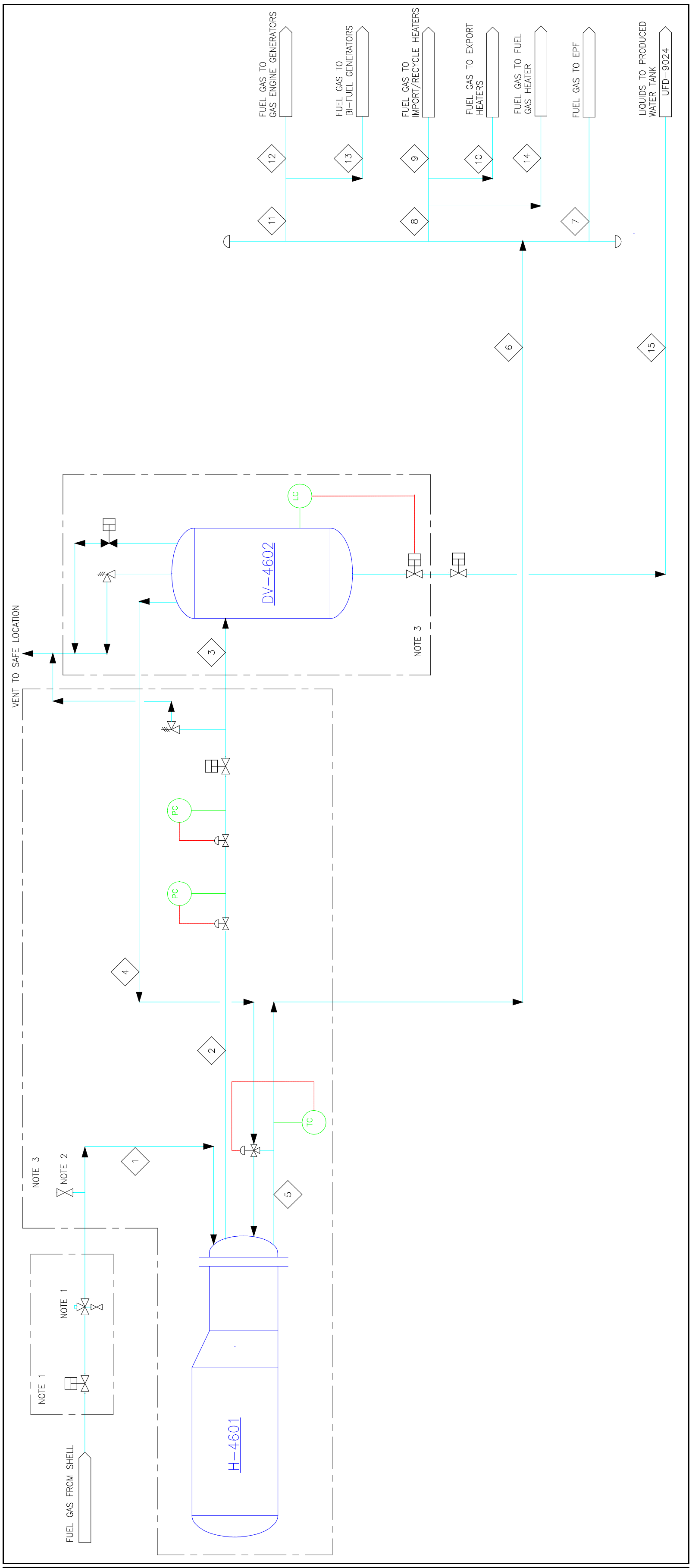
APPENDICES

A1: FUEL GAS SYSTEM - PFD



A2 - FUEL GAS BALANCE

Table 14: Heat and Mass Balance

	1		2		3	
STREAM	NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN
FLUID	VAPOUR	VAPOUR	VAPOUR	VAPOUR	MIXED	MIXED
VAPOUR FLOW (kg/hr)	2267	2370	2267	2370	2240	2341
VAPOUR DENSITY (kg/m^3)	97.44	97.44	85.17	85.55	5.66	5.68
VAPOUR MW	18.96	18.96	18.96	18.96	18.96	18.96
LIQUID FLOW (kg/hr)	-	-	-	-	26.11	28.3
LIQUID DENSITY (kg/m^3)	-	-	-	-	701.26	701.51
PRESSURE (barg)	100.0	100.0	100.0	100.0	5.7	5.7
TEMPERATURE (^{o}C)	25	25	45.6	44.8	1.7	0.7

4		5		6		7	
NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN
VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR
2240	2341	2240	2341	2240	2341	0	1552
5.66	5.68	4.63	4.66	5.38	5.38	5.38	5.38
18.79	18.78	18.79	18.78	18.79	18.78	18.79	18.78
0	0.0	-	-	-	-	-	-
701.26	701.51	-	-	-	-	-	-
5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
1.7	0.7	58.8	57.0	15.0	15.0	15.0	15.0

8		9		10		11	
NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN
VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR
1517	1585	1084	1132	401	420	723	756
5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38
18.79	18.78	18.79	18.78	18.79	18.78	18.79	18.78
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

12		13		14		15	
NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN	NORMAL	DESIGN
VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	VAPOUR	MIXED	MIXED
723	756	0	592	32	33	0	0
5.38	5.38	5.38	5.38	5.38	5.38	1.25	1.26
18.79	18.78	18.79	18.78	18.79	18.78	99.16	98.73
-	-	-	-	-	-	25.73	27.9
-	-	-	-	-	-	707.51	707.84
5.7	5.7	5.7	5.7	5.7	5.7	0.0	0.0
15.0	15.0	15.0	15.0	15.0	15.0	-0.4	-1.5

B1 - CALCULATION: FUEL GAS SCRUBBER

Feed data under normal case and worst case (Fuel gas with heater failure) scenarios.

Fluid Property	Unit	Value	
		Normal case	Worst case
Temperature (T)	^{o}C	0.70	-26.11
Pressure (P)	Kpa	673	673
Liquid Density (ρ_l)	kg/m³	701.6	688.0
Vapor Density (ρ_v)	kg/m³	5.68	8.78
Mixed Density (ρ_m)	kg/m³	5.75	6.45
Liquid Mass Flow (F_L)	kg/h	28.3	59.6
Vapor Mass Flow (F_V)	kg/h	2341	2302
Inlet Mass Flow (F_M)	kg/h	2370	2362
Liquid Volume Flow (Q_L)	m³/h	4.03E-02	8.65E-02
Vapor Volume Flow (Q_V)	m³/h	412.4	366.2

Using Stokes law, Ref 3: $V_V = K\left(\frac{\rho_l - \rho_v}{\rho_v}\right)^{0.5}$ **Eqn. B1-1**

$A = \frac{Q_V}{V_V}$ and $L_l = \frac{Q_l \times T}{A}$ **Eqn. B1-2, B1-3**

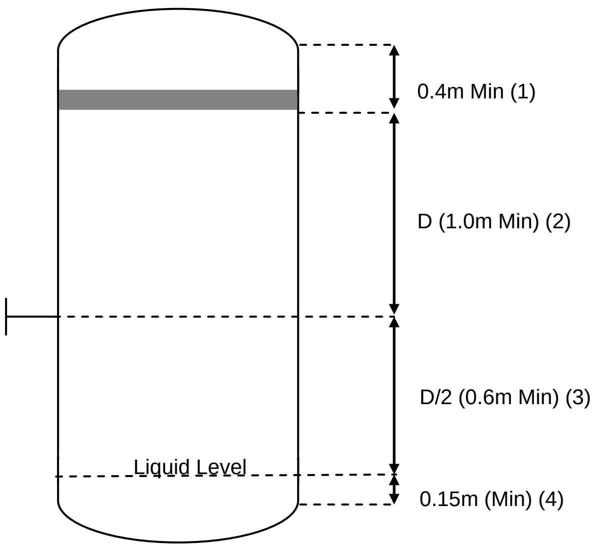
Where:

V_V = max allowable vap vel (m/s)
K = constant
ρ_l = liquid density (kg/m³)
T = holdup time (mins)
L_l = liquid depth (m)
ρ_V = vap density (kg/m³)
A = cross sectional area (m²)
Q_V = vap volumetric flowrate (m³/s)
Q_l = liquid volumetric flowrate (m³/s)

For a vertical separator of height < 3 m,K = 0.037m/s, From (Eqns. 10 - 12), the following is calculated:

	Unit	Normal case	Worst case	
V_v	m/s	0.41	0.33	
A	m^2	0.28	0.31	
D	mm	597	631	≈ 600mm
T	mins	10	10	
L_l	m	2.38E-02	5.10E-02	0.15 (Min)

Sketch



1 =	0.4	m
2 =	1	m
3 =	0.60	m
4 =	0.15	m
Tan-Tan =	2.15	m

B2 - CALCULATION: PRESSURE REDUCTION STATION

The control valve sizing is carried out as per GPSA (Ref. 8) and (Ref. 10)

Gas lines:

The valve sizing equations used is: $Cv = \frac{w}{N_8 F_P P_1 Y}\sqrt{\frac{T_1 Z}{XM}}$ **Eqn. B2-1**

where,
- q, fluid volumetric flowrate in m^3/hr
- w, fluid mass flowrate in kg/hr
- N_8, numerical constant = 94.8
- F_p, pipe geometry factor
- P_1, fluid inlet pressure in bara
- P_2, fluid outlet pressure in bara
- M, fluid molecular weight
- T, gas inlet temperature in K
- Z, compressibility factor

Y, expansion factor is calculated by: $Y = 1 - \frac{X}{3F_k X_T}$ **Eqn. B2-2**

(Y should not be less than 0.67. Also X should not exceed FkXc for gas)

Where, Fk, ratio of spec. heats is calculated by: $Y = 1 - \frac{X}{3F_k X_T}$ and $X_T = (\Delta P / P_1)$ **Eqn. B2-3, B2-4**

Two-phase flows:

The valve sizing equation used is: $Cv = \frac{w}{N_6 F_p}\sqrt{\frac{f_f}{\Delta p_f \gamma_f} + \frac{f_g}{\Delta p_g \gamma_g Y^2}}$ **Eqn. B2-5**

where,
- w, fluid mass flowrate in kg/hr
- N_6, numerical constant = 27.3
- F_p, pipe geometry factor
- f_f, weight fraction of liquid phase
- f_g, weight fraction of vapor phase
- Δp_f, pressure drop for liquid phase in bara
- Δp_g, pressure drop for vapor phase in bara
- γ_f specific weight (mass density) in kg/m^3 (for liquid phase)
- γ_g specific weight (mass density) in kg/m^3 (for vapor phase)

Actual pressure drops are used for Dpf and Dpg, but with individual limiting pressures:

$\Delta p_f = F_L{}^2 (p_1 - F_F p_v)$ and $\Delta p_g = F_k x_T p_1$ **Eqn. B2-6, B2-7**

Summary of results:

		PCV 1	PCV 2
Inlet temperature	oC	44.84	9.33
Outlet temperature	oC	9.33	0.70
Inlet pressure	barg	100	19
Outlet pressure	bar	19	5.73
CV	-	1.51	8.33
Valve type	-	Globe	Globe

B3 - CALCULATION: PRESSURE SAFETY VALVES

Design Data

Operating pressure	83.0	psig	5.7	barg
Design pressure	100	psig	6.9	barg
Relieving pressure set point	100	psig	6.9	barg
Operating temperature	492.6	°R	0.50	°C

	Fire	Non-fire	
Allowable over pressure	21	10	%
Relieving pressure	121	110	psig
	8.3	7.6	barg
Relieving temperature	684.8	629.2	°R
	107.3	76.4	°C
	225.1	169.5	°F

Relieving temperature: $T_1 = \left(\frac{P_1}{P_n}\right)T_n$ **Eqn. B3-1**

Where:
P_1 = Relieving pressure
P_n = Operating temperature
T_n = Operating temperature

Closed Outlet Case: Relieving rate (vapour relief)

$$A = \frac{W}{CK_d P_1 K_b K_c}\sqrt{\frac{TZ}{M}}\text{, where } C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$ **Eqn. B3-2, B3-3**

W (relief load)	2,341	kg/hr	5,161lb/hr
k (ratio of specific heats)	1.255	-	
C (co-efficient)	342.7	-	
Kd (co-efficient of discharge)	0.975	-	API RP 520 [3.6.2.1.1]
Kb (capacity correction factor)	1.0	-	API RP 520 [3.6.2.1.1]
Kc (rupture disc correction)	1.0	-	API RP 520 [3.6.2.1.1]
Z (compressibility)	0.9906	-	
M (molecular weight)	19.0	-	
T (relieving temperature)	629.2	R	76.4°C
P1 (relieving pressure)	124.5	psia	
A (effective discharge area)	0.711	in²	

Closed Outlet Case: Relieving rate (liquid relief)

$$A = \frac{Q}{38K_d K_w K_c K_v}\sqrt{\frac{G}{p_1 - p_2}}$$ **Eqn. B3-4**

Q (flow rate)	28.3	kg/hr	6.3bbl/d	0.2USGPM
Kd (co-efficient of discharge)	0.65	-	API RP 520 [3.8.1.2]	
Kw (back pressure correction)	1.0	-	API RP 520 [3.8.1.2] - assuming P2 / P1 > 0.15	
Kc (combination correction)	1.0	-	API RP 520 [3.8.1.2]	
Kv (viscosity correction)	1.0	-	API RP 520 [3.8.1.2] - preliminary estimate	
G (specific gravity)	0.702	-	at flowing temperature	
p_1 (relieving pressure)	110	psig		
p_2 (back pressure)	3.0	psig	(assumed)	
A (preliminary discharge area)	0.001	in²		

$$\text{Re} = \frac{Q(2800 \times G)}{\mu\sqrt{A}}$$ **Eqn. B3-5**

μ (absolute viscosity)	0.555	cP	at flowing temperature
A (effective discharge area)	0.11	in²	from API Std 526 (standard orifice areas)
Re (Reynold's Number)	1.95E+3	-	
Kv (viscosity correction)	0.941		N_{Re} adjusted value
A (effective discharge area)	0.001	in²	

Closed Outlet Case: PSV sizing

A (total discharge area)	0.712	in²	(vapor + liquid relief)

PSV selection

A (maximum discharge area)	0.712	in²
Relief orifice designation	H	Ref. 6
Valve body rating	150	lb
Valve body size	1.5 x 3	Minimum size

Note: the PSV was sized for other cases such as fire and control valve failure. The closed case was the largest relief load.

B4 - CALCULATION: FUEL GAS LINES

The lines are numbered as per the PFD – Figure 6

INPUT

Stream Number	**Unit**	**1**	**2**	**3**	**4**	**5/6**	**15**
Fluid		Vapor	Vapor	Mixed	Vapor	Vapor	Liquid
Pressure	(kPa)	10100	10100	674	674	674	674
Temperature	(C)	25.00	45.00	0.70	0.70	15.00	0.70
Molecular weight		18.96	18.96	18.96	18.78	18.78	98.73
Vapor Vol. Flow	(m^3/h)	24.32	27.61	412.29	412.15	435.13	-
Vapor Density	(kg/m^3)	97.44	85.85	5.68	5.68	5.38	-
	(lb/ft3)	6.08	5.36	0.35	0.35	0.34	
Vapor Mass Flow	(kg/h)	2370	2370	2341	2341	2341	-
Liquid Vol. Flow	(m^3/h)	-	-	0.04	-	-	0.04
Liquid Density	(kg/m^3)	-	-	701.50	-	-	701.50
	(lb/ft3)	-	-	43.79	-	-	43.79
Mixture density	(kg/m^3)	-	-	5.75	-	-	-
Liquid Mass Flow	(kg/h)	-	-	28.28	-	-	28.28
Gas Viscosity	(cP)	0.015	0.015	0.011	0.011	0.010	-
Liquid/Mixed Viscosity	(cP)	-	-	0.4302	-	-	0.549
Line SCH'D		120	120	40	40	40	80
Nominal diameter	(in)	4	4	4	4	4	2
Inside diameter	(in)	3.62	3.62	4.03	4.03	4.03	2.07
	(mm)	92.05	92.05	102.26	102.26	102.26	52.50
C		100	100	100	100	100	

OUTPUT

Fluid Vel.	(m/s)	1.02	1.15	13.94	13.94	14.72	0.01
Erosional vel. (V_e)	(ft/s)	40.55	43.20	166.97	167.93	172.55	-
	(m/s)	12.36	13.17	50.89	51.19	52.59	-
Reynolds no. (Re)		6.01E+05	5.98E+05	1.90E+04	7.70E+05	7.94E+05	3.47E+02
Moody fr. factor (f)		0.0175	0.0195	0.0256	0.0175	0.017	0.031
Resis. Co-efficient (K)		19.01	21.18	-	17.11	16.62	59.05
ΔP	(bar/100m)	0.01	0.01	0.14	0.09	0.10	5.54E-06

WFL Max velocity	(m/s)	45.72	45.72	45.7-61	45.7-61	45.7-61	0.6-1.8
WFL Max ΔP	(bar/100m)	0.45-1.13	0.45-1.13	0.11-0.22	0.11-0.22	0.11-0.22	0.09

Note
1. The lines are selected such that they meet the criteria for ΔP (bar/100m) and velocity. The company's internal standard for is used.
2. The distribution lines are to be a piping minimum size of 2" (NB)

C1 - BLOWDOWN VOLUME

	Section	OD	WT	ID		Area	l	passes	Total L	
		in	in	in	m	m^2	ft		ft	m
1	Preheater Inlet	2.375	0.344	1.687	0.0428	0.0014	150	-	150	45.72
2	Preheater	2.375	0.344	1.687	0.0428	0.0014	18	4	72	21.95
3	Preheater Outlet	4.5	0.531	3.438	0.0873	0.0060	20	-	20	6.09

4	Scrubber Inlet	4.5	0.237	4.026	0.1023	0.0082	5	-	5	1.52
5	Scrubber	-	-	48	1.2192	1.1675	8	-	8	2.44
6	After heater	4.5	0.237	4.026	0.1023	0.0082	18	4	72	21.95
7	Heater Outlet	4.5	0.237	4.026	0.1023	0.0082	150	-	150	45.72

Vol	Pressure	Vol @ atm	@ 6.9 barg
m^3	barg	m^3	m^3
0.07	100	6.59	0.96
0.03	100	3.16	0.46
0.04	100	3.65	0.53

0.01	6.9	0.09	0.01
3.32	6.9	22.92	3.32
0.18	6.9	1.24	0.18
0.38	6.9	2.59	0.38

Sections 4 / 5 / 6 / 7 Total:	26.84	3.89
All Sections Total:	40.25	5.83

C2 - BLOWDOWN: DISPERSION

Figure 6: Dispersion Envelope Showing UFL and LFL (Upper and Lower Flammability Limits)

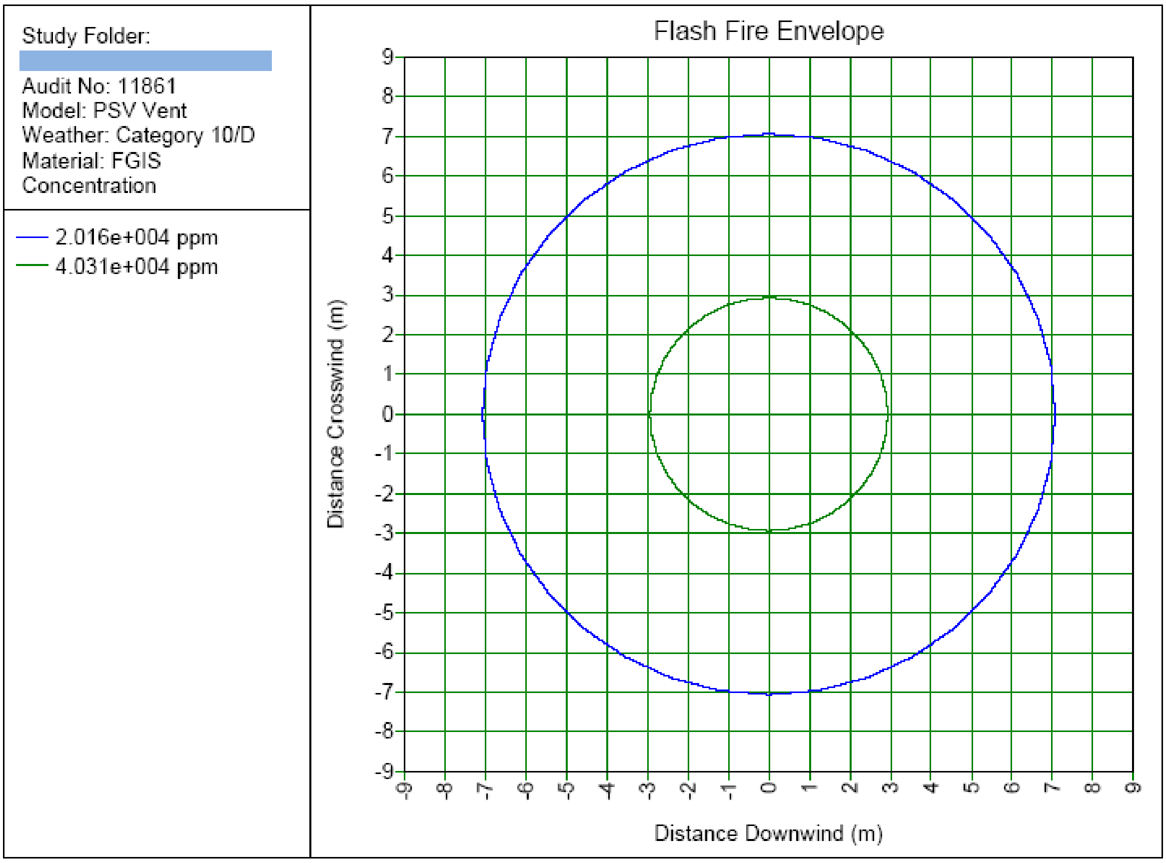
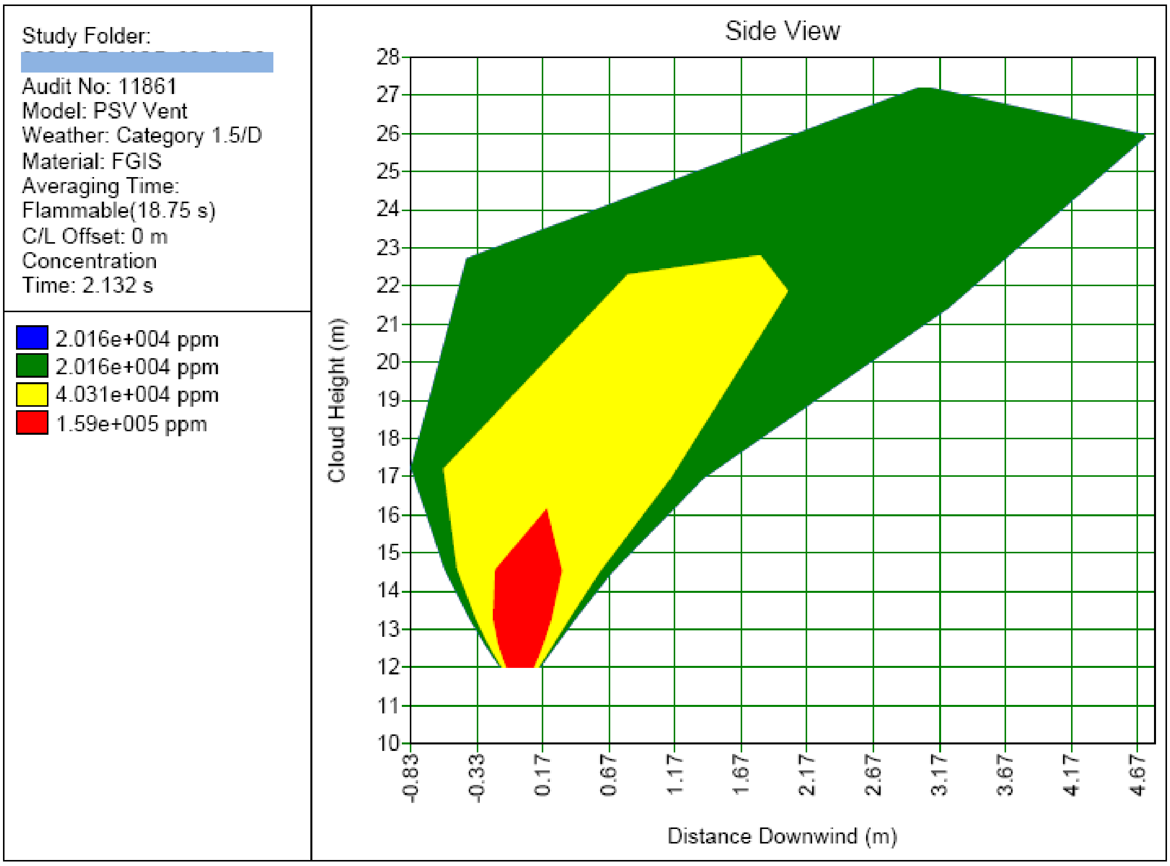


Figure 7: UFL and LFL – Side View



C3 - RADIATION: ISOPLETHS

Figure 8: Radiation Isopleths

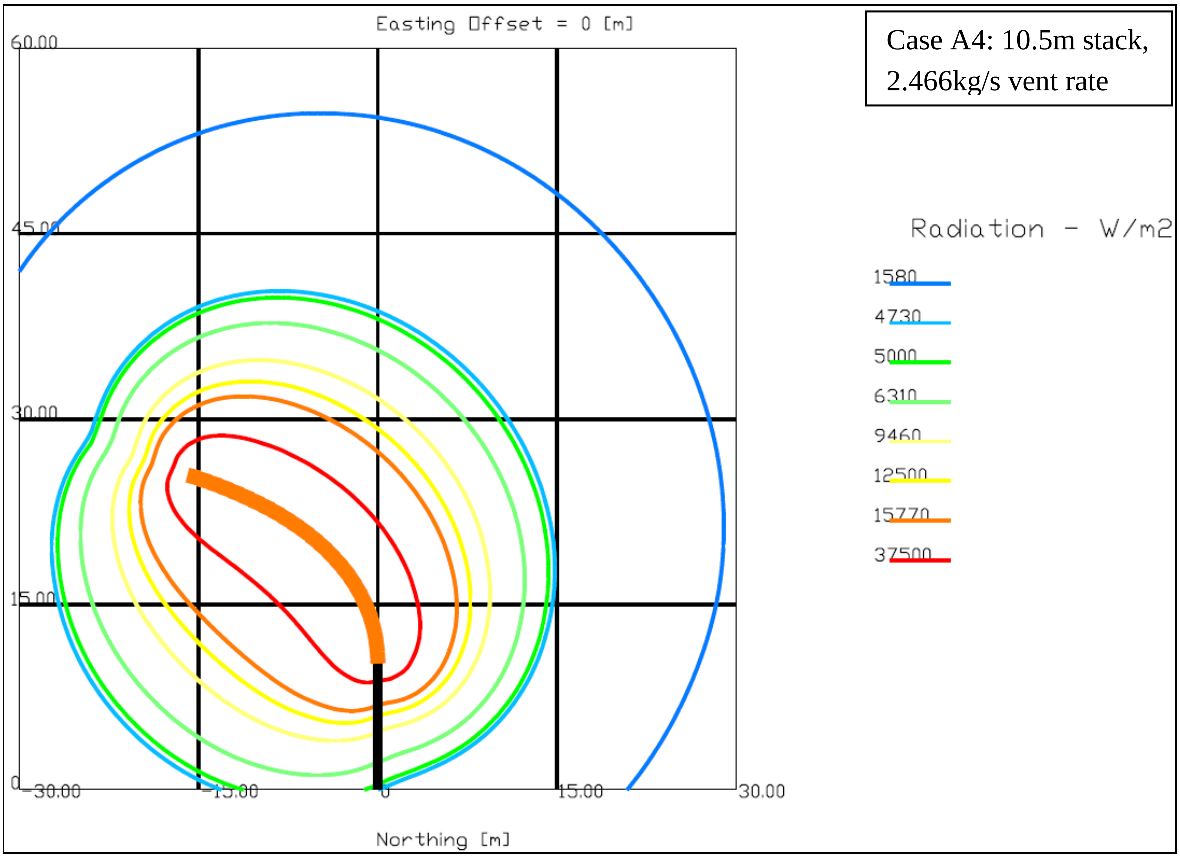


Figure 9: Blowdown – Pressure vs Time