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The Optimum Scenario for Connecting New Flare Capacity to Existing Flare Systems

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Abstract

Flares are safety systems designed to protect site facilities, people, and environmental pollution. The vented gas from equipment is mainly used to control the pressure of the processes. In oil companies, the production capacity of wells decreases over time due to well depletion. To maintain productivity, a new compression project is being constructed to improve well recovery with lower reservoir production and pressure. For such the new compression it is required to create a vent system for it to relieve pressure in case of normal and emergency conditions. In this work, two scenarios are proposed to connect the venting system of the new project to the existing flare systems. These two scenarios are staggered and conventional blowdowns. The study of the two proposed scenarios was based on the allowable design capacity of the current flare systems. In addition, a comparison was made between the two proposed scenarios and two other scenarios from the literature. The results showed that the conventional blowdown scenario is the most effective to meet the current blowdown criteria and existing design requirements.

Keywords: *Flare; Gases blowdown; Gepressurization; Conventional blowdown, Sequential blowdown; Staggered blowdown.*

1. Introduction

Flares are safety devices that prevent unburned gases from entering the atmosphere. These gases burn or explode if they reach an ignition source. In plants, exhaust gases flammable during normal and emergency conditions are collected in the piping headers and delivered for safe disposal to the flare system. There are two levels of flaring, flaring occurs during a plant emergency, and flaring is the treatment of waste gases during normal operation [1-3].

The important performance parameters of the flaring system are divided into three parameters. The first parameter is the smokeless capacity which is the maximum flow of waste gases to the flare without producing a high level of smoke. The second parameter is the thermal radiation from the flare as a function of waste gas composition and flowrate. The third parameter is the excessive noise parameter which injures equipment, people and plant property [3-5]. Flare emission is very difficult to measure due to flares burning in the open. Flaring gases produce emissions such as nitrogen oxides (NO_2), sulfur oxides, greenhouse gases (CO_2), carbon monoxide (CO) and volatile organic compounds.

To maintain environmental regulations, pollution control is required. Also, waste gas flowrate and composition are generally not controllable. However, there is great interest in reducing pollutant emissions from flare. Many strategies highlight the minimization of flaring gases from either plant practices or new equipment. Therefore, flare is a safe emergency that releases waste gases in petroleum processes. Flare provides safe disposal of waste gases streams from plants by burning these gases under a controlled system. Thus, people or equipment are not exposed to any problems or risks.

To keep environmental regulation to control pollution [4]. The size of the flare system must be designed correctly to accommodate the amount of waste gases during depressuring at peak flow. As when the hydrocarbons are burned, the resulting gases react with oxygen to form carbon dioxide and many by-products that depend on the efficient conversion of hydrocarbons [5-7].

A large amount of waste gases during the blowdown operation must be disposed of simultaneously. It is ensuring that there is sufficient flare discharge capacity without violating hydraulic constraints in pipeline flare.

Incorrect size of the flare system leads to excessive pressures, excessive vibrations and high radiation that exceeds the capacity of the flare tip. Therefore, it is necessary to determine the size of the restriction orifices, flow control devices and various connections for the flare. Besides the type of metal used for the flare connections [8-11].

Vessel depressurization is inherently a dynamic process. At the start of depressurization, higher pressures inside the vessel result in a higher driving force and thus higher mass flow through the orifice directed to the flare header. As the pressure in the vessel decreases over time, so does mass flow. By staggering or implementing a time delay between the opening times of multiple orifices, you can reduce the peak mass flow to the flare header and prevent the system from being overloaded. A staggered blowdown technique is applied in such situations to optimize the flare system design capacity. The staggered blowdown system should be designed to optimize the flare system design capacity while maintaining the ability to blowdown the facility as quickly and safely as possible. Staggered blowdown analysis is particularly useful for capital expansion and process revamp studies, where new process units may be added and tied into existing flare disposal systems. It can also be useful in front-end engineering and design to reduce the size of the flare header piping and thus save on capital expenditures [12-14].

The present study proposed staggered blowdown and conventional blowdown scenarios for connecting new flare capacity to existing flare systems. The results were compared with two scenarios from the literature to select the optimum one.

2. Case study

The case study in this work is taken from Fouad *et al.* [15]. It is an existing petroleum company located in Egypt. This company started a remote facility. This facility is equipped with a small flaring system capacity of 416,800 kg/hr. As time passed, the production capacity of wells decreased due to wells depletion. For maintaining productivity, a new compression project is designed to improve the recovery as the reservoir production rate and pressure decrease. Such a new project required has no flare system for its facilities vent and disposal in normal and in the emergency case. Since there are two existing independent flare systems, one for phase-1 facilities and the other flare for phase-2 facilities. It is proposed to connect the new compression unit facilities vent and disposal to these existing flare systems.

In this work two scenarios are proposed for connecting the compression flare unit to the existing flares system. The proposed scenarios are as following:

1) Scenario-1: Staggered blowdown
2) Scenario-2: Conventional blowdown

The two proposed scenarios and another two scenarios from the literature are competitive to find the optimum one for connecting the flare system to the existing flare systems.

2.1. Phase-1 and Phase-2 flare systems

The processing facilities for Phase-1 and 2 are similar and in summary, consist of cooling and separation of the production fluids with subsequent recombination of gas and condensate for export and local water treatment and disposal. The sizing case for each high-pressure (HP) flare system is the blowdown case. Each HP flare system has the same capacity based on the design blowdown rate for Phase-1 facilities. The point of discharge to the atmosphere is located away from people and equipment. It is assumed to have been constructed as a result of original design thermal radiation calculations associated with flaring and through other safety considerations in the event of ignition failure. For safe incineration and radiation considerations flares are located at a remote point from the plant. Figure 1 shows Phase-1 and Phase-2 flare systems.

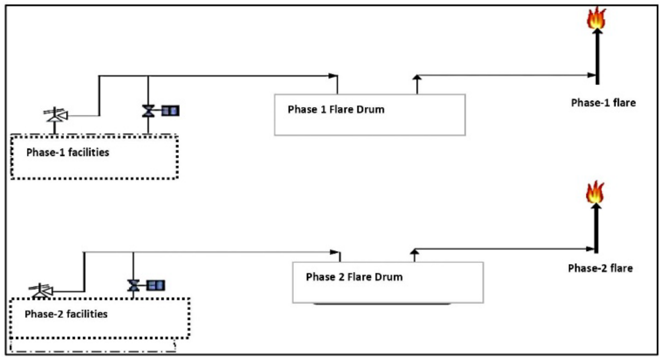

Figure 1. The two existing flare system

Phase 1 and Phase-2 process facilities consist of 12 and 7 Blowdown valves (BDVs), respectively. These BDVs are used in the emergency shutdown to release the process plant facility hazardous hydrocarbon. The blowdown philosophy complies with the API 521 standards [16] to release the hazardous hydrocarbon gas from the maximum pressure at 131 barg during the emergency to be reduced in 15 minutes to reach 7 barg. In such case, the processing facility can be maintained safely in case of emergency fire or even in the preliminary gas release. The process facility emergency shutdown valves and blowdown valves are described in Figure 2 for Phase-1 and Figure 3 for Phase-2.

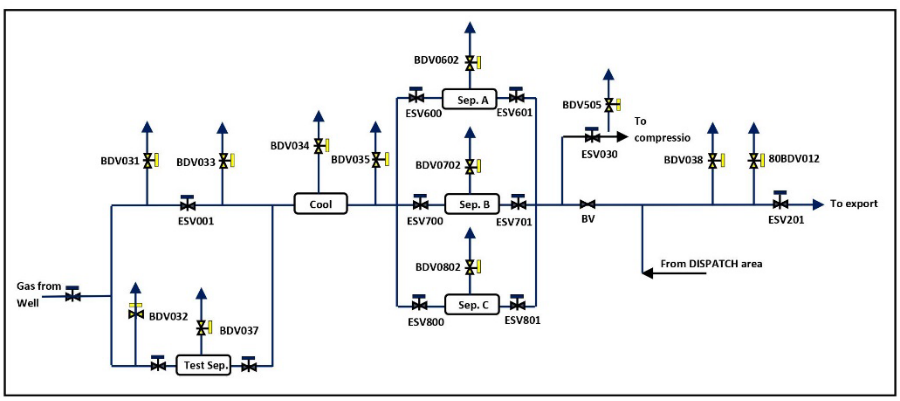

Figure 2. Process flow diagram for Phase-1

The total flared gas during blowdown of phase-1 and phase-2 equals the sum of flared gas calculated for each blowdown valve individually. All system depressuring is considered in the moment of emergency case activation to achieve the depressuring through 15 minutes.

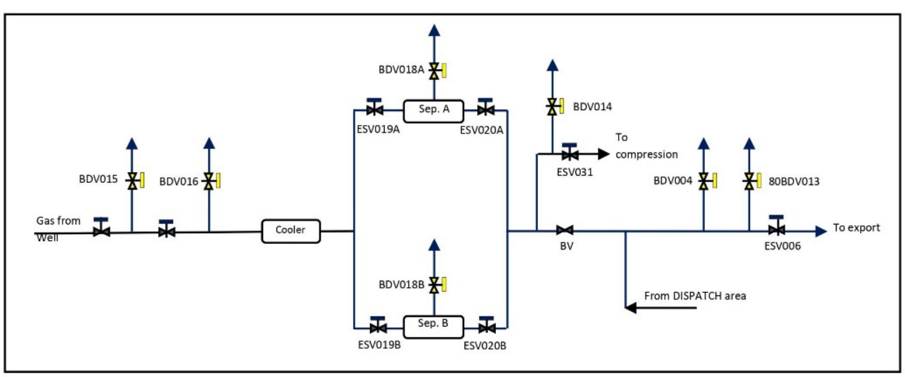

Figure 3. Process flow diagram for Phase-2

2.2. Compression flare unit

The new compression flare unit consists of three systems. These three systems are a compression system (Figure 4, a), a condensate handling system (Figure 4, b) and a fuel system (Figure 4, c). The new compression unit facilities include 12 BDVs that are used for the emergency shutdown to release the hazardous hydrocarbon from the process plant facilities.

In this work, we propose different scenarios to connect this new compression flare unit with the two existing flare systems of Phase-1 and Phase-2.

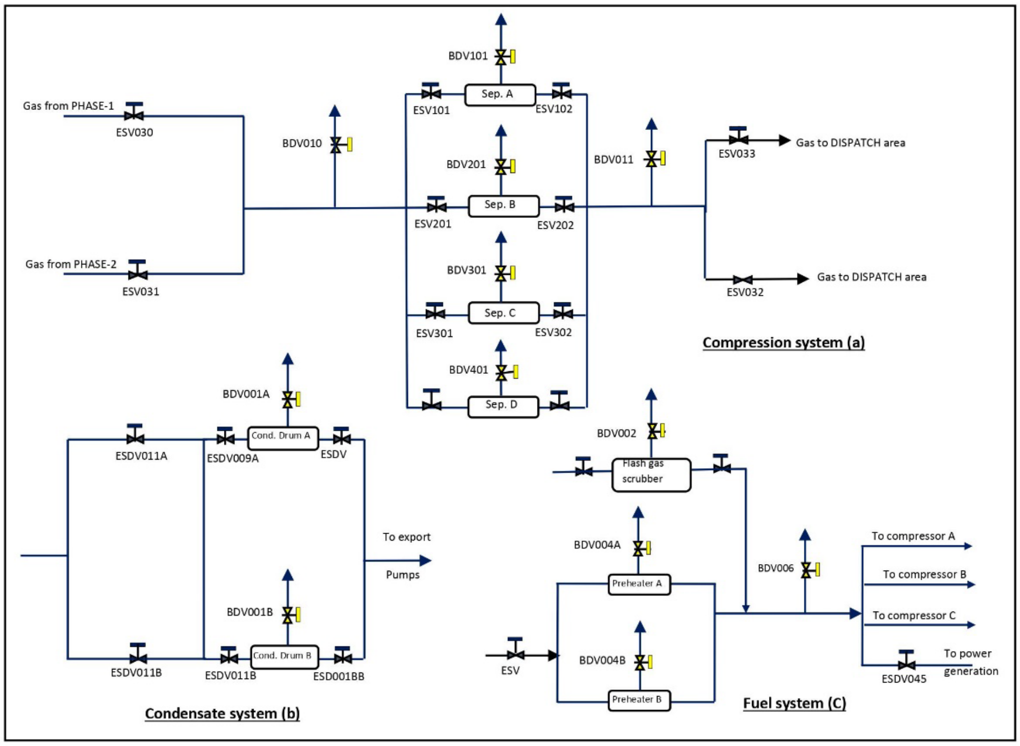

Figure 4. Compression unit facilities blowdown valves

3. Methodology

3.1. Scenario 1: Staggered blowdown:

The staggered blowdown technique can be achieved via adding a series of blowdown valves for the single equipment [14]. Thus, the depressuring occurs once the first blowdown valve opens to the flare relieving a certain peak flow. After a period of time, the equipment pressure decreases and so the peak flow. To maintain the peak flow with the maximum relieving capacity, a second blowdown valve will open. Hence to maintain approximately the maximum peak flow constant per time, a series of valves will open in time intervals. To determine the number of staggered BDVs for each equipment. A preliminary criterion was developed to decide which blowdown valves can be most effective to meet the blowdown criteria and existing flare design requirements. The main factor is that all BDVs handle peak flow rate more than 40,000 Kg/hr will be staggered by two or three staggered BDVs to meet the design requirements and blowdown criteria.

3.2. Scenario-2: Conventional blowdown

In this scenario, the blowdown philosophy according to the API 521 standards [16] can release the hazardous hydrocarbon gas from the design pressure (138 barg) during the emergency to reach 50% of design pressure (69 barg) in 15 minutes instead of reaching to 7 barg in 15 minutes. In such a case, the total flared gas from Phase-1 and Phase-2 will be lower than the design flare capacity. Therefore, adding the compression flare unit to one of the two existing flaring systems can be achieved according to the allowable design capacity.

3.3. Blowdown considerations

Blowdown is the removal of liquid contents of vessels and equipment to prevent its contribution to a fire or explosive incident. Blowdown is similar to depressurization but involves liquids rather than gases. A liquid blowdown should never be sent to facility flare that is designed to only handle gaseous materials. A liquid release of the flare may result in a flare out, and if the flare is elevated, a shower of liquids on the process facilities can result. Ideally, liquid blowdown should be routed to facilities that are specifically designed to handle large quantities of liquid materials.

Each equipment automatic depressurization has been carefully calculated to identify the peak blowdown rate during the external fire and at gas detection conditions (non-fire condition).

The following is a list of common blowdown considerations, which were considered, where appropriate, for all items of equipment including but not limited to [17-20]:

- Power failure
- Compressor seal failure
- External fire (shutdown operation)
- Gas detection
- Instrument air failure
- Maintenance blowdown
- Both flare systems (phase-1 and phase-2) are designed for the same capacity of 416,800 kg/hr.

4. Results and discussion

The case study is simulated using Aspen HYSYS program Version 11 and Aspen Flare System Analyzer Version 11 to perform the process plant facility blowdown scenarios for phase-1 and phase-2. All scenarios are simulated based on API-521 standard fire case. All process equipment is sized according to the mechanical datasheet. All pipes are selected according to the type of metal from which the pipe is made, schedule and nominal diameter and thus the length of the pipeline to determine the proposed size of that pipe.

4.1. Scenario 1: Staggered blowdown results

The results show that the staggered blowdown philosophy can accomplish the blowdown criteria and meet the existing flares design criteria. The valves having flowrate above 40,000 kg/hr are 5 valves in phase-1 (30-BDV-031, 30-BDV-602, 30-BDV-702, 30-BDV-802, 80-BDV-012), 3 valves in phase-2 (40-BDV-015, 40-BDV-016, 80-BDV-013) and 6 valves in the compression unit (80-BDV-010, 80-BDV-101, 80-BDV-201, 80-BDV-301, 80-BDV-401, 80-BDV-011). The peak flow by every staggered BDV (kg/hr), orifice area and diameter required for every staggered BDV, initial conditions for every staggered BDV and the operating time of each staggered valve are presented in Tables 1, 2 and 3 for phase-1, phase-2 and compression unit, respectively. Figure 5 shows the blowdown flowrate profile and pressure profile for the valve 80-BDV-012 as an example of the staggered valve in phase-1 when the valve is single (without staggering) and when the valve is staggered to small valves (2 staggered valves). Figure 6 shows blowdown flow rate profile and pressure profile for the valve 40-BDV-015 as an example of the staggered valve in phase-2. Figure 7 shows blowdown flowrate profile and pressure profile for the valve 80-BDV-401 as an example of the compression unit.

Table 1. Staggered BDVs data for Phase-1 (Scenario 1)

	Single	Phase-1: 30-BDsV-031:Staggered BDVs		
Tag No	30-BDV-031	30-BDV-031 S1	30-BDV-031 S2	30-BDV-031 S3
Peak flow rate kg/hr.	43301			
Orifice area,mm^2	742.1	381.5	298	1060
Orifice size, mm	30.74	21.90	19.40	36.50
Initial pressure, barg	131	131	75.9	30.4
Initial temperature, °C	110	110	102.0	94.7
Opening time, sec	0	0	300	600
	Single	Phase-1: 30-BDV-602/702/802:Staggered BDVs		
Tag No	30-BDV-602/702/802	30-BDV-602/702/802 S1	30-BDV-602/702/802 S2	30-BDV-602/702/802 S3
Peak flow rate kg/hr.	56846	19299	19413	43613
Orifice area,mm^2	883.9	300	150.00	1598.00
Orifice size, mm	33.55	19.54	13.70	44.90
Initial pressure, barg	131	131	80.7	45.9
Initial temperature, °C	57.8	57.8	24.5	-5.8
Opening time, sec	0	0	300	600
	Single	Phase-1: 80-BDV-012: Staggered BDVs		
Tag No	80-BDV-012	80-BDV-012 S1	80-BDV-012 S2	NA
Peak flow rate kg/hr.	56099	19299	48749	
Orifice area,mm^2	873	300	1073	
Orifice size, mm	33.34	19.54	36.8	
Initial pressure, barg	131	131	65.6	
Initial temperature, °C	57.8	57.8	12.3	
Opening time, sec	0	0	450	

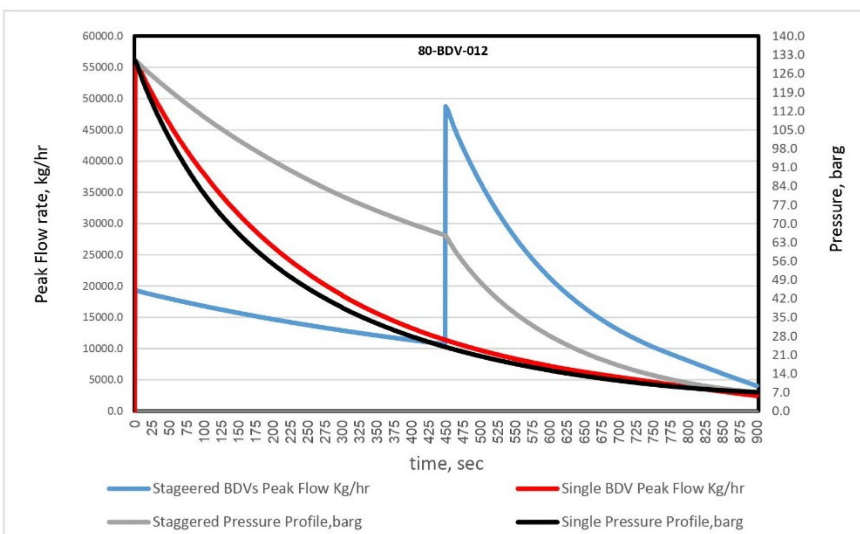

Figure 5. The blowdown flow rate and pressure profile for valve 80-BDV-012

As shown in Figure 5 the blowdown valve 80-BDV-012 in Phase-1 is staggered to 2 valves. The required final pressure (7 barg) and time (15 minutes) required for flaring are divided between the two staggered valves. The first staggered valve will open at a design pressure of 131 bar with a peak flow of 19,299 kg/hr until the pressure reaches 65.5 barg at 450 sec (7.5

min). At this point, the peak flow is reduced. To maintain the maximum flowrate, the second staggered valve will open at 48,749 kg/h. and at 65.6 barg to reach 7 barg at 900 seconds (15 minutes).

Table 2. Staggered BDVs data for Phase-2 (Scenario 1)

	Single	Phase-2: 40-BDV-015: Staggered BDVs		
Tag No	40-BDV-015	40-BDV-015 S1	40-BDV-015 S2	40-BDV-015 S3
Peak flow rate kg/hr.	46248	23128	23128	23133
Orifice area,mm^2	776.4	387.5	302.5	1065
Orifice size, mm	31.44	22.21	19.53	36.60
Initial pressure barg	131	131	76.5	31.1
Initial temperature, °C	90	90	82.0	72.5
Opening time, sec	0	0	300	600
	Single	Phase-2: 40-BDV-016: Staggered BDVs		
Tag No	40-BDV-016	40-BDV-016 S1	40-BDV-016 S2	NA
Peak flow rate kg/hr.	83543	41776	53568	
Orifice area,mm^2	1403	700	1389	
Orifice size, mm	38.05	29.85	41.8	
Initial pressure barg	131	131	59.3	
Initial temperature, °C	90	90	77.91	
Opening time, sec	0	0	450	
	Single	Phase-2: 80-BDV-013: Staggered BDVs		
Tag No	80-BDV-013	80-BDV-013 S1	80-BDV-013 S2	NA
Peak flow rate kg/hr.	73139	41798.8944	38160	
Orifice area,mm^2	1137	650	888	
Orifice size, mm	38.05	28.77	33.4	
Initial pressure barg	131	131	45.5	
Initial temperature, °C	57.8	57.8	-6.8	
Opening time, sec	0	0	450	

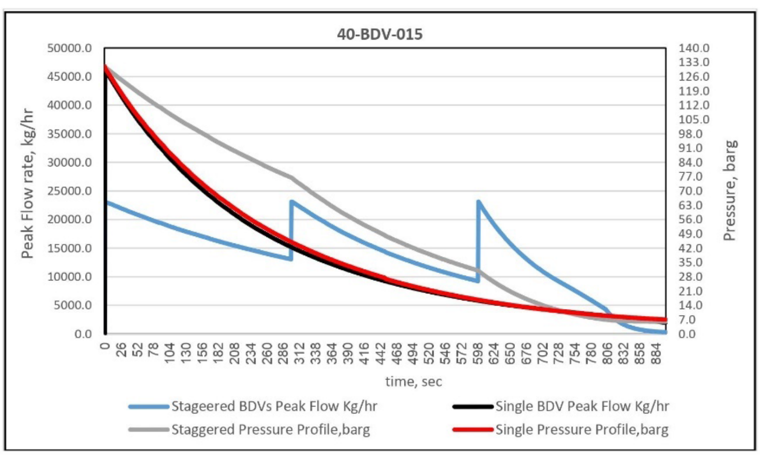

Figure 6. The blowdown flow rate and pressure profile for valve 40-BDV-015

Figure 6 shows the blowdown valve 40-BDV-015 in phase-2 staggered into 3 valves. The first staggered valve opens at a flowrate of 23,128 kg/h. at a pressure of 131 barg for 300 seconds (5 minutes). While the second staggered valve opens at 23,128 kg/h and a pressure of 76.5 barg for another 300 seconds. The last staggered valve completes the burn cycle from 31.1 bar to 7 bar in the last 300 seconds.

Table 3. Staggered BDVs data for compression unit (Scenario 1)

	Single	Compression: 80-BDV-010 :Staggered BDVs		
Tag No	80-BDV-010	80-BDV-010 S1	80-BDV-010 S2	NA
Peak flow rate kg/hr.	101223	34997	99570	
Orifice area,mm^2	2457	850	3903.13	
Orifice size, mm	55.93	32.9	62.00	
Initial pressure barg	85	85	50.18	
Initial temperature, °C	47.58	47.58	14.51	
Opening time, sec	0	0	450	
	Single	Compression: 80-BDV-101/301:Staggered BDVs		
Tag No	80-BDV-101/301	80-BDV-101/301 S1	80-BDV-101/301 S2	80-BDV-101/301 S3
Peak flow rate kg/hr.	52350	18739	19520	45573
Orifice area,mm^2	1229	440	210	1794
Orifice size, mm	39.56	23.67	16.27	47.57
Initial pressure barg	95	95	63.4	37.9
Initial temperature, °C	72.8	72.8	43.0	12.8
Opening time, sec	0	0	300	600
	Single	Compression: 80-BDV-201/401: Staggered BDVs		
Tag No	80-BDV-201/401	80-BDV-201/401 S1	80-BDV-201/401 S2	80-BDV-201/401 S3
Peak flow rate kg/hr.	42646	21315	21355	21362
Orifice area,mm^2	956.4	478	307	850
Orifice size, mm	34.89	24.67	19.68	32.75
Initial pressure barg	100.2	100.2	56.7	26
Initial temperature, °C	76.71	76.71	35.3	-4.7
Opening time, sec	0	0	300	600
	Single	Compression: 80-BDV-011:Staggered BDVs		
Tag No	80-BDV-011	80-BDV-011 S1	80-BDV-011 S2	NA
Peak flow rate kg/hr.	87377	31894	73544	
Orifice area,mm^2	1370	500	1643	
Orifice size, mm	41.76	25.23	45.53	
Initial pressure barg	130	130	63.4	
Initial temperature, C	57.8	57.8	10.7	
Opening time, sec	0	0	450	

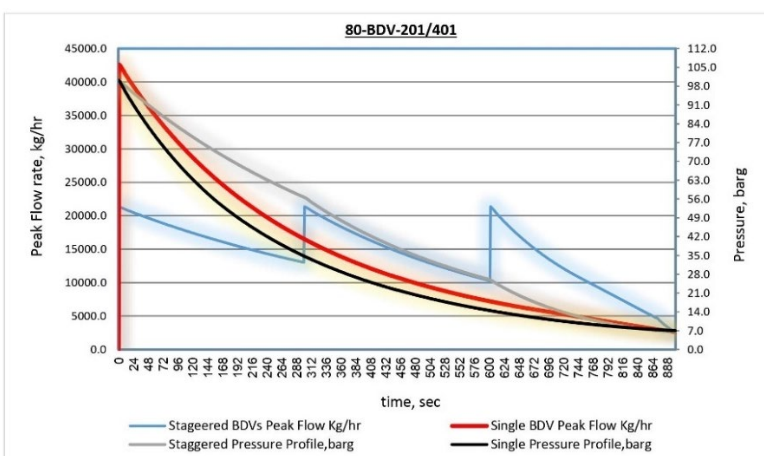

Figure 7. The blowdown flow rate and pressure profile for valves 80-BDV-201/401 in compression unit

If this scenario is applied, all new staggered valves will cost $202,500 as shown in Table 4. Also, this scenario would require a new system of uninterrupted power supply (UPS) or emergency diesel generator system. The UPS operates efficiently in the case of a total power failure at the plant. When the normal power supply is interrupted, the backup power supply (UPS) should start automatically. UPS should run for 30 minutes or more, depending on the total depressurization cycle time. UPS costs $10,000.

Table 4. New Staggered valves cost estimation

Location	Tag No	Number of staggered BDVs	Valve Size (in)	Cost/Valve ($)	Total Cost ($)
PH-1	30-BDV-031	3	2″	3000	9000
PH-1	30-BDV-032	1	2″	3000	3000
PH-1	30-BDV-033	1	2″	3000	3000
PH-1	30-BDV-034	1	2″	3000	3000
PH-1	30-BDV-035	1	3″	3750	3750
PH-1	30-BDV-602	3	2″	3000	9000
PH-1	30-BDV-702	3	2″	3000	9000
PH-1	30-BDV-802	3	2″	3000	9000
PH-1	30-BDV-505	1	2″	3000	3000
PH-1	30-BDV-038	1	3″	3750	3750
PH-1	30-BDV-037	1	6″	6000	6000
PH-1	80-BDV-012	2	6″	6000	12000
PH-2	40-BDV-015	3	2″	3000	9000
PH-2	40-BDV-016	2	6″	6000	12000
PH-2	40-BDV-018A	2	3″	3750	7500
PH-2	40-BDV-018B	2	3″	3750	7500
PH-2	40-BDV-004	1	3″	3750	3750
PH-2	80-BDV-013 (NEW VALVE)	2	10″	5250	10500
PH-2	80-BDV-014 (NEW VALVE)	1	3″	3750	3750
Compression	80-BDV-010	2	4″	4500	9000
Compression	80-BDV-101	3	2″	3000	9000
Compression	80-BDV-201	3	2″	3000	9000
Compression	80-BDV-301	3	2″	3000	9000
Compression	80-BDV-401	3	2″	3000	9000
Compression	80-BDV-011	2	10″	10500	21000
Compression	80-BDV-001A/B	1	2″	3000	3000
Compression	80-BDV-002	1	1″	1500	1500
Compression	80-BDV-004A/B	1	2″	3000	3000
Compression	80-BDV-006	1	1″	1500	1500
Total Cost					202,500

The staggered blowdown is used to limit the cumulative flaring load from various flaring sources within the flare design capacity. In addition, minimizing depressurization time to the least protects pool and pipe rupture.

4.2. Scenario 2: Conventional blowdown results

The process plant facility as an existing system contains 19 BDVs for individual Phase-1 and Phase-2 flare headers and stack. We will calculate the individual valve peak flow to determine the commingle streams to feed the flare tip through the flare header and flare.

The conventional blowdown scenario is based on the API-521 standard fire case. The blowdown philosophy complies with the API 521 standards to release the hazardous hydrocarbon gas from the design pressure during the emergency to be reduced in 15 minutes to reach 50% of design pressure. In such case, the processing facility can be maintained safely in case of emergency fire or even in the preliminary gas release. Total flared gas during blowdown equals the sum of calculated flared gas peak flow of valves individually during blowdown considering all system depressuring in the moment of emergency case activation to achieve the depressuring through 15 minutes. The total peak flow calculated for Phase-1, Phase-2 and compression units are as described in Tables 5, 6 and 7, respectively.

Table 5. Total flared gas during blowdown for Phase-1 (Scenario-2)

		Gas m^3	Liq. m^3	barg	ºC	barg	mm^2/mm	kg/hr.
40-BDV-015	From flow line receiver package, production header package, to air coolers	33.5851		138	90	69	178.5/15.07	11304
		26.816	6.7691					
40-BDV-016	From inlet to air coolers, test separator, to inlet of production separators	61.38		138	90	69	317.5 /20.1	10051
		49.02	12.36	138	90	69	317.5 /20.1	10051
40-BDV-018A	Production separator	30.69		138	57.8	69	127 /12.7	8650
		15.34	15.35					
40-BDV-018B	Production separator	30.69		138	57.8	69	127 /12.7	8650
		15.34	15.35					
40-BDV-004	From outlet of Production Separators to Phase-2 battery limit ESV at Salam Pipeline	14.613		138	57.8	69	76.3 /9.85	5379
		14.61	0.003					
80-BDV-013 (NEW VALVE)	Interpiping between comp. Discharge & tie-in	47.6795		138	57.8	69	196 /15.8	13350
		47.67	0.0095					
80-BDV-014 (NEW VALVE)	Interpiping between phase-2 & tie-in	15.122		138	57.8	69	63.34 /8.98	4315
		15	0.122					
TOTAL FLARED GAS DURING BLOWDOWN, kg/hr.								71750
Flare Designed Flow Rate, kg/hr.								416800
Excess of Design %								83%
Shortage of Design %								0.00%

Table 6. Total flared gas during blowdown for phase-2 (Scenario 2)

EBDV TAG	P&ID # SERVICE	Total volume;		Initial Press.	Initial Temp.	Final Pressure	Orifice area /Diameter	Blowdown Rate
		Gas m^3	Liq. m^3	barg	ºC	barg	mm^2/mm	kg/hr.
40-BDV-015	From flow line receiver package, production header package, to air coolers	33.5851		138	90	69	178.5/15.07	11304
		26.816	6.7691					
40-BDV-016	From inlet to air coolers, test separator, to inlet of production separators	61.38		138	90	69	317.5 /20.1	10051
		49.02	12.36	138	90	69	317.5 /20.1	10051
40-BDV-018A	Production separator	30.69		138	57.8	69	127 /12.7	8650
		15.34	15.35					

Table 6. Total flared gas during blowdown for phase-2 (Scenario 2) (continued)

40-BDV-004	From outlet of Production Separators to Phase-2 battery limit ESV at Salam Pipeline	14.613		138	57.8	69	76.3 /9.85	5379
		14.61	0.003					
80-BDV-013 (NEW VALVE)	INTERPIPING BETWEEN comp. Discharge & tie-in	47.6795		138	57.8	69	196 /15.8	13350
		47.67	0.0095					
80-BDV-014 (NEW VALVE)	Interpiping between phase-2 & TIE-IN	15.122		138	57.8	69	63.34 /8.98	4315
		15	0.122					
TOTAL FLARED GAS DURING BLOWDOWN, kg/hr.								71750
Flare Designed Flow Rate, kg/hr.								416800
Excess of Design %								83%
Shortage of Design %								0.00%

Table 7. Total flared gas during blowdown for Compression unit (scenario 2)

EBDV TAG	SERVICE	TOTAL VOLUME;		Initial Press.	Initial Temp.	Final Pressure	Orifice Area / Diameter	Blowdown Rate
		GAS; m^3	LIQ; m^3	Barg	^oC	Barg	mm^2/mm	kg/hr
80-BDV-010	SEPARATORS OUTLET TO COMPRESSION SUC-	123.865		138	47.58	69	515 (25.6)	36770
		123.86	0					
80-BDV-101	COMPRESSION MACHINE TRAIN A	62.2747		138	72.76	69	246 (17.7)	15755.7
		57.8	4.4747					
80-BDV-201	COMPRESSION MACHINE TRAIN B	47.3951		138	76.71	69	185.6 (15.3)	11703
		44.55	2.8451					
80-BDV-301	COMPRESSION MACHINE TRAIN C	62.2747		138	72.76	69	246 (17.7)	15755.7
		57.8	4.4747					
80-BDV-401	COMPRESSION MACHINE TRAIN D	47.3951		138	76.71	69	185.6 (15.3)	11703
		44.55	2.8451					
80-BDV-011	COMPRESSION DISCHARGE TO EXISTING EXPORT FACITILIES	58		138	57.8	69	237.8 (17.4)	16200
		58	0					
80-BDV-001A	CONDENSATE SUCTION DRUM A	28.165		72	57.8	36	131.9 (12.96)	2180
		19.595	8.57					
80-BDV-001B	CONDENSATE SUCTION DRUM B	28.194						2180
		19.624	8.57					
80-BDV-002	FLASH GAS PREHEATER	0.068		72	57.8	36	0.36 (0.68)	12.15
		0.068	0					
80-BDV-004A	HP FUEL GAS PREHEATER	2.304		138	57.44	69	10.29(3.6)	702
		2.304	0					
80-BDV-004B	HP FUEL GAS PREHEATER B	2.258						
		2.258	0					
80-BDV-006	HP FUEL GAS KO DRUM	7.291		44	50	22	36.9 (6.8)	725
		7.291	0					
TOTAL FLARED GAS DURING BLOWDOWN, kg/hr								113686.5
Flare Designed Flow Rate, kg/hr								416800
New Identical Flare, Excess of Design %								73%
New Identical Flare, Shortage of Design %								0.00%

It is noted from Tables 5, 6 and 7 that:

1-The total flared gas directed to Phase-1 flare will be 82879 Kg/hr. (which is lesser than the design flare capacity by 80% of design capacity 416800 Kg/hr.))

2-The total flared gas directed to Phase-2 flare will be 71750 Kg/hr. (which is lesser than the design flare capacity by 83% of design capacity 416800 Kg/hr.)
3-The below Table 8 shows the excess % of existing flares design capacity, during the compression blowdown on phase-1 and phase-2 flares.

Table 8. Excess % of existing flares design capacity, during blowdown for Scenario-2

	Phase-1	Phase-2	Compression	Phase-1 +Compression	Phase-2 + Compression
Total flared gas, kg/hr	82879	71750	113688	196567	185438
Flares design capacity, kg/hr	416800	416800		416800	416800
Excess of design %	80%	83%		53%	45%
Shortage of design %	0	0		0	0

Table 8 showed that when compression facilities vent and disposing are added to phase-1, the flare capacity will be 196,567 kg/hr. and this value is lower than the design capacity by 53%. On the other hand, when the compression facilities vent and disposing are added to phase-2, the total flared gas will be 185,438 kg/hr. which is lower than the design capacity by 45%. So, in this scenario, it is possible to connect compression facilities to Phase-1 or Phase-2 when the pressure is decreased from the design pressure to 50% of it in 15 minutes.

4.3. Comparing the proposed scenarios with scenarios from literature

The results of the two proposed scenarios in this work were compared with two other scenarios applied to the same case study in the literature presented by Fouad *et al.* [15]. The first scenario from the literature was based on the implementation of a new independent flare system for the new compression unit. Where the total gas flared during the blowdown is equal to the sum of all the individual blowdown valves in each system individually. The second scenario is the sequence of compression unit flare system to Phase-1 or Phase-2 flare systems. This sequential scenario is based on relieving the compression unit flare system to Phase-1 or Phase-2 flare system after the piping and equipment of Phase-1 or Phase-2 reach 7 barg at 15 minutes.

The results of implementing a new flare system as presented by Fouad *et al.* [15] is that 417,150 kg/hr flared gas will be directed to Phase-1 flare system, 347518 kg/hr flared gas will be directed to Phase-2 flare system and 400738 kg/hr flared gas will be directed to compression unit new flare system as illustrated in column 4 of Table 9. Flared gas directed to Phase-1 exceeds the design capacity (416,800 kg/hr) by 0.08% but this increase matches the flare design margin. The cost of implementing the new flare system was $2,400,000.

On the other hand, the results of sequential the compression unit flare to Phase-1 or Phase-2 after Phase-1 or Phase-2 flare system reached the final pressure of 7 barg at 15 minutes were as follows:

If the compression unit flare is sequenced to the Phase-1 flare system, the flared gas from the compression unit that will be routed to phase-1 flare system after the Phase-1 equipment and piping have reached the final pressure was 418812.49 kg/h. This flowrate exceeds design capacity by 0.5% but this increase matches design margins. But if the compression unit flare is sequenced to the Phase-2 flare system after phase-2 equipment and piping reaches the final pressure, the flared gas was 415604.49 kg/h. The application of this scenario will require the installation of a UPS system. This system is based on the use of different zones interference to avoid any failure that causes direct flaring. A comparison of these two scenarios with the two proposed in this work is shown in Table 9.

It is noted from Table 9 that the conventional blowdown is the most effective scenario for application as it does not require any new additional systems. Sequential blowdown presented by Fouad *et al.* [15] comes in second because it only requires $10,000 for a new UPS system. Staggered blowdown is third to be applied as it requires $202,500 for the new staggered blowdown valves and $10,000 for the new UPS system. Implementation of a new compression unit flare system is the last choice at a cost of $2,400,000. This last choice may be the only choice when the other choices are not applicable.

Table 9. The overall results of the suggested four scenarios

Blowdown scenarios / Items	Staggered blowdown (7 barg within 15 min)	Conventional blowdown (50% of design pressure in 15 min)	Suggested scenarios from literature [15]	
			Implementing a new flare system (7 barg within 15 min) system	Sequential Blowdown (7 barg within 15 min)
Phase-1 flared gas	25897.8 kg/hr.	82879 kg/hr.	417,150 kg/hr.	418812.49 kg/hr.
Phase-2 flared gas	16824.88 kg/hr.	71750 kg/hr.	347,518 kg/hr.	415604.49 kg/hr.
Compression flared gas	38535.47 kg/hr.	113688 kg/hr.	400,738 kg/hr.	400738.49 kg/hr.
Phase-1 flared gas (design capacity kg/hr)	416,800 kg/hr.			
Phase-2 flared gas (design capacity kg/hr)	416,800 kg/hr.			
Cost if exist	$202,500 for new staggered blowdown valves and $10,000 for new UPS system to avoid multiple flaring at the same time.	-	$2,400,000 for new flare as it is not applicable to direct compression loads to either Phase-1 flare or Phase-2 flare.	$10,000 for new UPS redundant system to avoid any failure causing direct flaring at the same time.

When comparing the four scenarios concerning safety analysis, it was found that the worst-case scenario is the scenario that may initiate flaring. Higher risks were expected in scenarios 1 (staggered blowdown) proposed in this work and sequential blowdown (suggested by Fouad *et al.*[15]) due to the additional UPS required to control the operations of BDVs during blowdown. The interference of the different zones in the UPS system is high-risk. If an unsuitable zone is selected, no action will be taken for the other zone in case of fire. To overcome these risks, periodic inspection and functional testing of BDVs is required to ensure that the BDVs will perform their designed function properly. Also, a highly reliable UPS system is required to ensure a safe blowdown operation. In addition, the UPS system failure rate needs to be correctly determined. Conventional blowdown may be the first optimal scenario and the implementation of a new flare system comes in the second because they provide minimal depressurizing requirements according to API521.

5. Conclusion

In this work, two scenarios are proposed for connecting the new compression unit flare system to two existing flare systems. The two scenarios are staggered blowdown and conventional blowdown. Two other scenarios from the literature applied to the same case study are discussed and compared with the two presented. These two scenarios are implementing a new flare and sequential blowdown system.

We can conclude that the conventional blowdown scenario proposed in this work is the optimal choice to be applied when connecting a new flare system with an existing one. This scenario does not require the installation of any new additional systems and provides minimum system blowdown requirements according to API521 standard. The second optimal scenario is the implementation of a new independent flare system for the new compression unit facilities. The addition of a new independent compression flare system will positively help to relieve the new compression surge volume in a minimum time as per the API521 standard in 15 minutes or less. Independent flare will not affect the depressuring time of the existing facilities, and additionally, the project will not be affected when one of the existing flares is under maintenance. But on the other hand, it will negatively affect the budget of the project as its cost is $2,400,000.

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