

The major sources of gas flaring and air contamination in the natural gas processing plants: A case study

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ABSTRACT

Global flaring and venting of natural gas is a significant source of greenhouse gas emissions and airborne pollutants that has proven difficult to mitigate. Devastating impact of such emissions both on the climate and environment makes it inevitable for researchers, environmentalists and policy makers to give remarkable focuses on this issue in recent times. This paper revolves around highlighting potential and critical situations, identifying the proper mitigation and focusing on the sources of flaring and contamination to reduce the generation of wastes from the gas processing plants of a domestic natural gas field in Iran. The flaring management of four domestic gas processing plants with the total capacity of 252 million cubic meter natural gas in a day plays an important role in the environmental pollution reduction. The inventory of emissions lists all the individual sources of air contamination in each gas processing plant and the quantities of the emissions. The major sources of gas flaring are the regeneration gas coming from the mercaptan removal unit in Phase 1, the sweeping gas consumption in the flare network in Phase 2 and 3, and the backup stabilization gas flaring in Phases 4 and 5. The adjustment of fuel gas consumption was conducted after the flare network back pressure has been calculated in Phase 2 and 3 by a Flare Net simulator. In order to address the excessive fuel gas network corrosion in Phases 6, 7 and 8, a modification was performed in this gas processing plant. Chemical de-emulsifier injection allowed for removing the debris build-up on the rebuilders tubes of the condensate stabilization column in Phases 4 and 5. The recycling regeneration gas of the mercaptan removal unit in Phase 1 reduced 55% of the gas flaring in this gas processing plant.

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1. Introduction

In the global petroleum and natural gas industry, flaring of unwanted flammable gases via combustion in open atmosphere flames is regarded as a major environmental concern in addition to wasting the valuable source of energy. Recent estimates from satellite data indicate that more than 139 billion m³ of gas are flared annually (Elvidge et al., 2009), an amount equivalent to 4.6% of the world natural gas consumption which totaled 3011 billion m³ in 2008 (BP, 2010). This amount of flaring produces approximately 281 million tons of CO₂ emissions annually (Johnson and Coderre, 2011). Emissions from flaring also contribute to the heating of the earth and enhance the natural greenhouse effect of the atmosphere and even climate changes (Azam and Farooq, 2005; Shu et al., 2010;

Nordell, 2003; Rahimpour et al., 2012) over the coming century. Gas flaring harms the health of the people through emissions that have been linked to cancers, asthma, chronic bronchitis, blood disorders, and other diseases (Nwankwo and Ogagarue, 2011; Nwaogu and Onyeze, 2010). Flaring can also be a source of pollutants such as particulate soot (Pohl et al., 1986; McEwen and Johnson, 2012), oxides of nitrogen (NO_x), sulfur oxides (SO_x), volatile organic compounds (VOCs) (Rahimpour and Jokar, 2012), unburned fuel (Johnson et al., 2001a,b; Johnson and Kostiuik, 2000), and other undesirable by-products of combustion (Stroscher, 2000). CO emissions are primarily due to mobile sources (National Air Pollutant Emissions Trends, 1900–1998).

The effects of gas processing plants on the environment play a major role in the public perception of the operations. Good social relations are valuable assets and attention to plant discharges plays a major part in maintaining local support (Rittmeyer, May 1991).

The framework convention on the climatic changes, which took effect in 1995, requires that nations prepare and publish the

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inventories of greenhouse gas emissions reduction (Draft Iranian Ambient Air quality standard, May 1998). The targets, which took effect during the period of 2008–2012, would require the emission reduction of approximately 30% at projected levels in 2010 (IPS-E-SF-860, July 1994). Even though the Kyoto Protocol may not come into force, most nations implement some programs to limit emissions. Controlling the emissions of volatile organic compounds (VOCs) and air toxics will significantly facilitate the operations. Although there have been studies indicating that emissions from mobile sources contribute considerably to these high ozone levels, the industrial sources of VOCs and nitrogen oxides are being controlled. Since refineries and chemical plants handle large quantities of volatile organic compounds (VOCs), some emissions of these compounds occur during normal operations. The largest source of VOCs is typically fugitive emissions (Mukhopadhyay and Moretti, 1993). The emissions of VOCs tend to be controlled due to the regulations which limit the emissions based on their potential to react with nitrogen oxides to form ozone and due to some toxic VOCs (Mochida et al., 2000).

Mitigating the effects of accidental releases of hazardous vapors has been the main focus of the recent regulations. There are

two general types of control strategies for the impact agents. The first type of control strategy is the source control in which the volume of a particular contaminant is minimized by the operation or process modifications and the second type, which is non-source control, reduces the contaminant generated by the source to an acceptable level before the contaminant enters the atmosphere.

A great emphasis has been placed on the source control in modern hydrocarbon processing operations. The technologies contributing to a reduction in the downstream level of source pollutants are costly, and they usually result in the destruction or consumption of valuable hydrocarbon compounds. One exception, where the hydrocarbons are not destroyed, is vapor recovery. In vapor recovery, recovered materials can be recycled to the processing operation, or used as fuel. Xu et al. (2009) investigated a general methodology on flare minimization for chemical plant start-up operations via plant wide dynamic simulation. Rahimpour and Jokar (2012) investigated the best method for recovering the flare gas of Farashband gas processing plant from the economic point of view. Zadakbar et al. (2008) presented the results of two case studies of reducing, recovering and reusing flare gases from

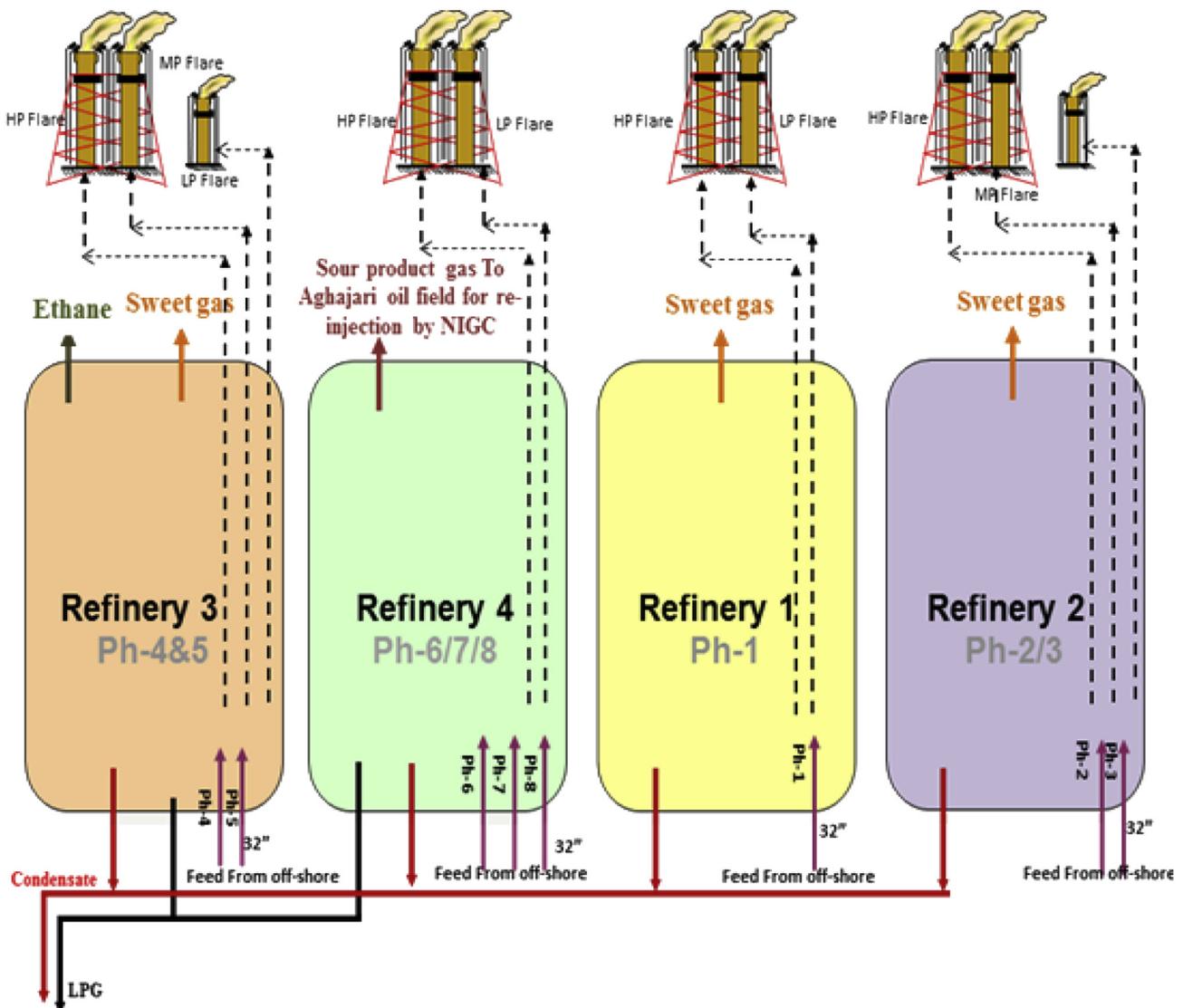


Fig. 1. The configuration of domestic gas processing plants.

the Tabriz Petroleum Refinery and Shahid Hashemi-Nejad (Khan-giran) Natural Gas processing plant (both in Iran).

Non-source control is also called end-of-pipe or stack control. Rahimpour (2008) investigated the conversion of CO₂ into methanol by catalytic hydrogenation as one of the most promising processes to stabilize the atmospheric CO₂ level. Zahedi et al. (2005) investigated a hybrid neural network model for the simulation of a differential catalytic hydrogenation reactor of carbon dioxide to methanol. Rahimpour and Mottaghi (2009) investigated the simultaneous removal of urea, ammonia, and carbon dioxide from industrial wastewater via the modeling and simulation of a hydrolyzer-separator loop. Rahimpour and Kashkooli (2004) developed a comprehensive model for the absorption of carbon dioxide into the promoted hot potassium carbonate solution.

Prior to finding the ways by which the emissions of various pollutants can be reduced, it is of great significance to determine and well analyze the major sources of flaring gas and air contamination. Regarding the point that Iran maintains the second largest reservoirs of natural gas in the world, the effects of gas processing plants on the environment is notable. The purpose of this study is to

identify the various sources of gas flaring in the domestic gas processing plants in Iran from both quantitative and qualitative viewpoint and mention the most important design factors influencing the flaring process. Moreover, some modifications made in the plants were highlighted and relevant effectiveness was discussed.

2. Process description in domestic gas processing plants

Fig. 1 shows the configuration and products of domestic gas processing plants. The region contains five gas processing plants in 10 Phases.

Fig. 2 indicates the schematic process diagram of Phase 1. In gas processing plant 1 or Phase 1, the 28.3 million cubic meters gas-mixed liquidities are first separated from the pure gas entered into the gas processing plant and then saturated gas is sweetened, moisture-removed, dew point set and mercaptan-removed. Every day, 25 million cubic meters of the produced and refined gas enters into the unified system. Being passed from the two stabilizing gas liquidity units, the separated gas liquidities are sent into

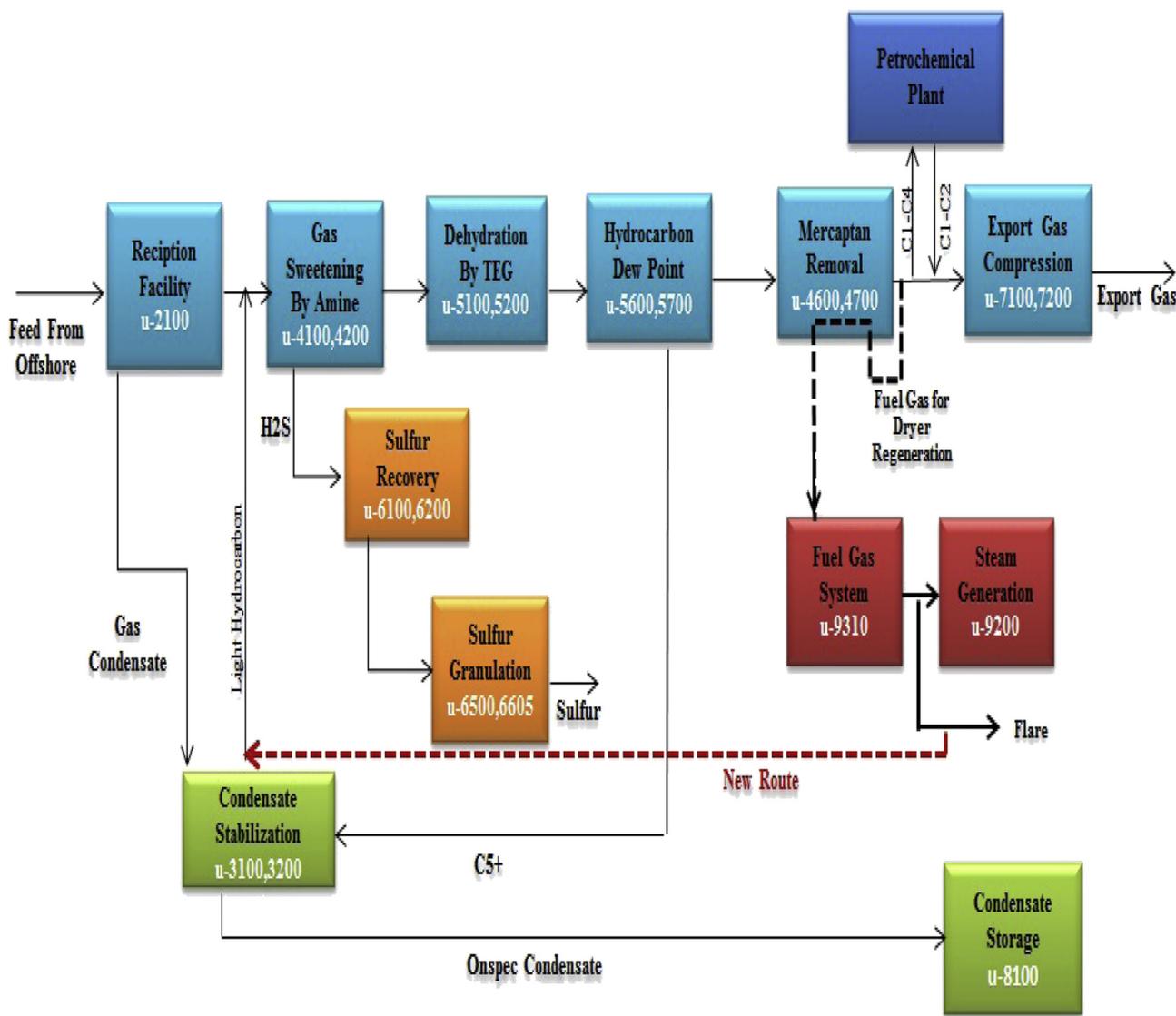


Fig. 2. Process block diagram of Phase 1.

the reserving tanks for export, and 40,000 barrels are produced daily. Also, the separated H₂S in the sweetening unit is sent to sulfur recovery units and 200 tons of granular sulfur is produced daily.

Fig. 3 illustrates the process block diagram of Phases 2 and 3. In gas processing plant 2 or Phases 2 and 3, 57.2 million cubic meters per day of the gas entered into the gas processing plant and mixed with 6 million cubic meters of the gas received from the gas processing plant 4 and enters into 4 gas processing plants, each with a capacity of 15.2 million cubic meters and then the refined gas is entered into the unified system. After performing the sweetening, moisture-removal, dew point set and mercaptan removal and being passed from two gas liquidity stabilizing units, the separated gas liquidities produce 81,250 barrels which are sent into the reserving tanks for export. In addition, the separated H₂S in the sweetening unit is sent to the sulfur recycling units to produce 400 tons granular sulfur each day.

Fig. 4 depicts the process description and different parts of Phases 4 and 5. In gas processing plant 3 or Phases 4 and 5,

56.5 million cubic meters of gas is separating from gas liquidities and sent to 4 gas refining units, each with a capacity of 14.1 million cubic meters daily. After performing the dew-removing process, the recycling, ethane refining, propane and butane refining and the storing, the setting of the gas dew point and the mercaptan-removing, each day 51.5 million cubic meters reined gas is produced and sent to the unified system through a 56-inch pipeline.

Fig. 5 shows the process diagram and sections of Phases 6, 7 and 8. Gas processing plant 4 or Phases 6, 7 and 8, has the largest gas establishment in the Middle East and has the capacity of 110 million cubic meters gas daily. Since the gas produced in this design is used for the gas injection into Aghajari oil fields veils, no gas sweetening unit is built in this gas processing plant. This gas processing plant has six moisture-removing rows and dew point settings: three gas liquidity stabilizing units and three propane and butane production units as well as side establishments which have the capacity to produce 104 million cubic meters of sour in a day.

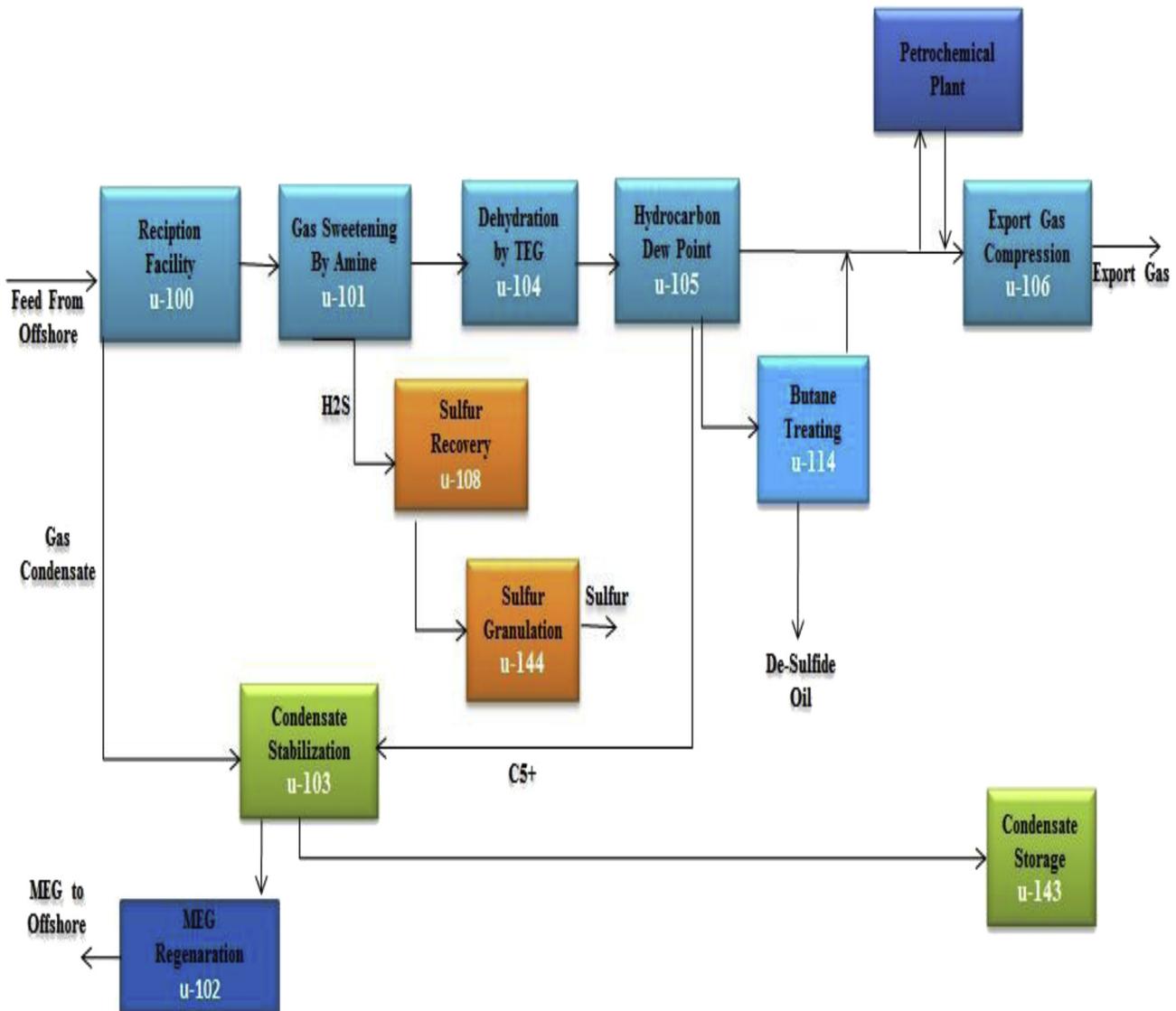


Fig. 3. Process block diagram of Phases 2 and 3.

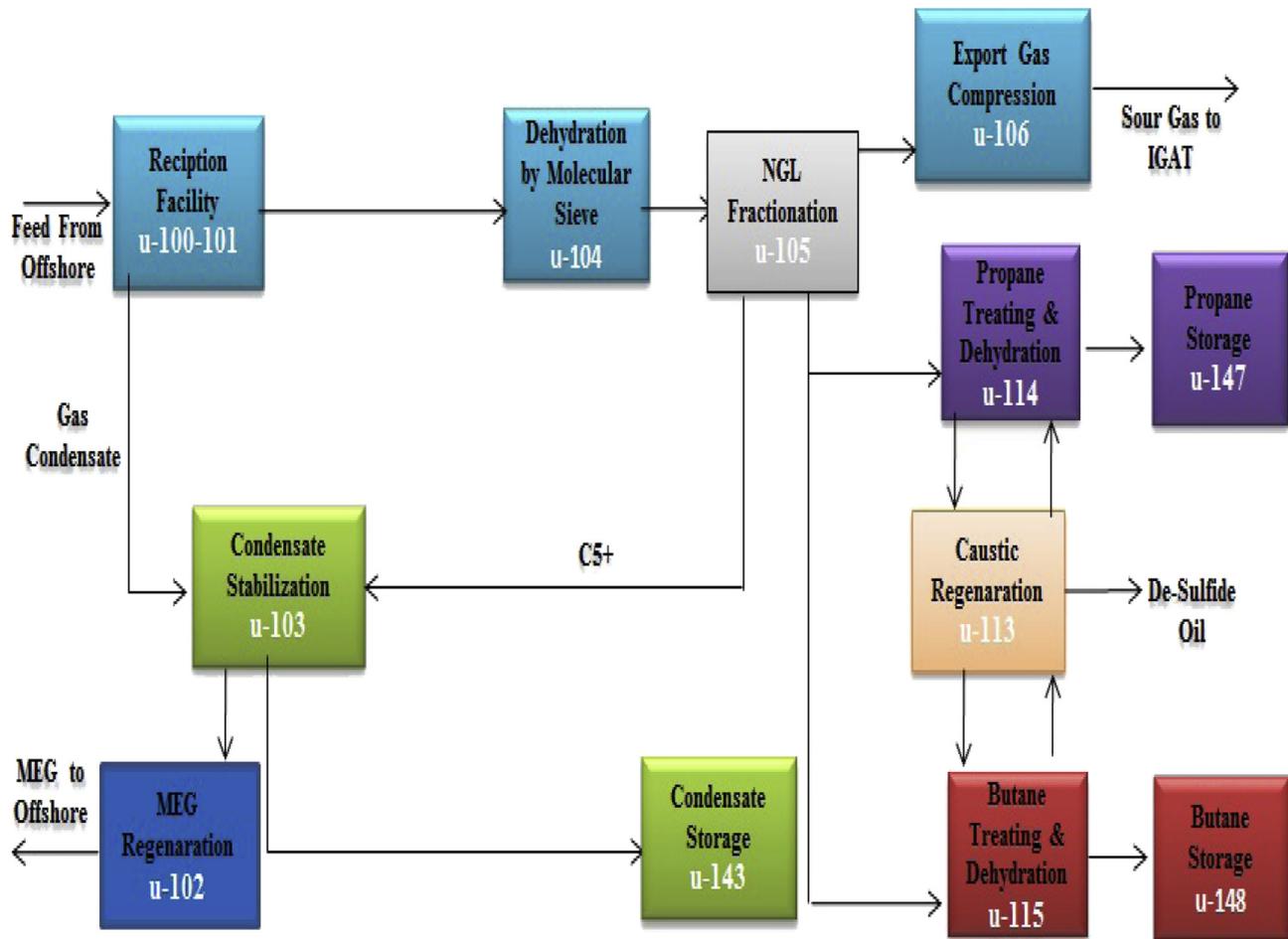


Fig. 5. Process block diagram of Phases 6, 7 and 8.

sweeping gas is six times as high as that of in the other plants. The sweeping gas must be injected at the beginning of the largest flare headers or sub-headers in order to keep the positive pressure in the whole flare system. The flow of sweeping gas into the flare network is normally a waste of valuable purge gas or product. For economic reasons the purge gas flow is normally minimum to ensure the safe pressure conditions within the flare network. The minimum sweeping gas flow rate is a function of the volumetric gas velocity. As per recommendation of the flare vendor, the sweeping gas flow rate for systems with the sealing device is 0.2 (ft/sec) and without the sealing device is 3 (ft/sec). The back pressure of the flare network in normal conditions (sweeping gas injection only) is necessary to change the volumetric velocity to the mass flow rate. A Flare Net simulator has been used for the flare header and sub-header, and the tail pipe back pressure is calculated as follows:

- Piping roughness for carbon steel: 0.04572 mm
- Piping roughness for stainless steel: 0.02540 mm
- Back Pressure: Back Pressure to be compatible with the Relief Valve type and BDV's restriction orifice as follows:
 - 10% of set pressure for the Conventional valve type.
 - 50% of set pressure for the balanced valve type.
 - 50% of pressure upstream orifice for the BDV's to ensure critical flow in the orifice.
 - Maximum pressure in the high pressure flare network: 12.5 barg.
- Continuous Flow (gas flow):

- Velocity for lines downstream relieving devices, sub-headers and headers:
- 0.35 Mach maximum and $\rho v^2 < 50\,000\text{ kg/m}^2\text{s}^2$

Table 2 shows the flare vendor's information for Phases 2 and 3 include data used for pressure drop calculation by the Flare Net simulator.

The sweeping gas volume was determined to verify the set point value of Phases 2 and 3 after pressure drop calculation in each sub-header by the simulator. The results show that the pressure of the flare network was overestimated to calculate the gas sweeping mass flow by the vendor. Considering the 5-bar pressure for LP (low pressure), the MP (medium pressure) and the HP (high pressure) flare networks tend to overestimate the sweeping gas flow rate calculation in Phases 2 and 3. The simulation result shows the average back pressure at sub header for different flare networks in Phases 2 & 3 is about 1.1 barg in normal flaring conditions. Table 3 shows the sweeping gas injected into the end of different sub-headers using 2-inch lines in design and modified case.

3.1.3. Recycling regeneration gas of the mercaptan removal unit in Phase 1 gas processing plant

A molecular sieve is used in the plant as adsorbents in the natural gas processing plant Phase 1 to remove mercaptan impurities from the natural gas before it is fed into the pipeline. The mercaptan removal units are equipped with the molecular sieve. The molecular sieve is designed to adsorb and to remove the lower

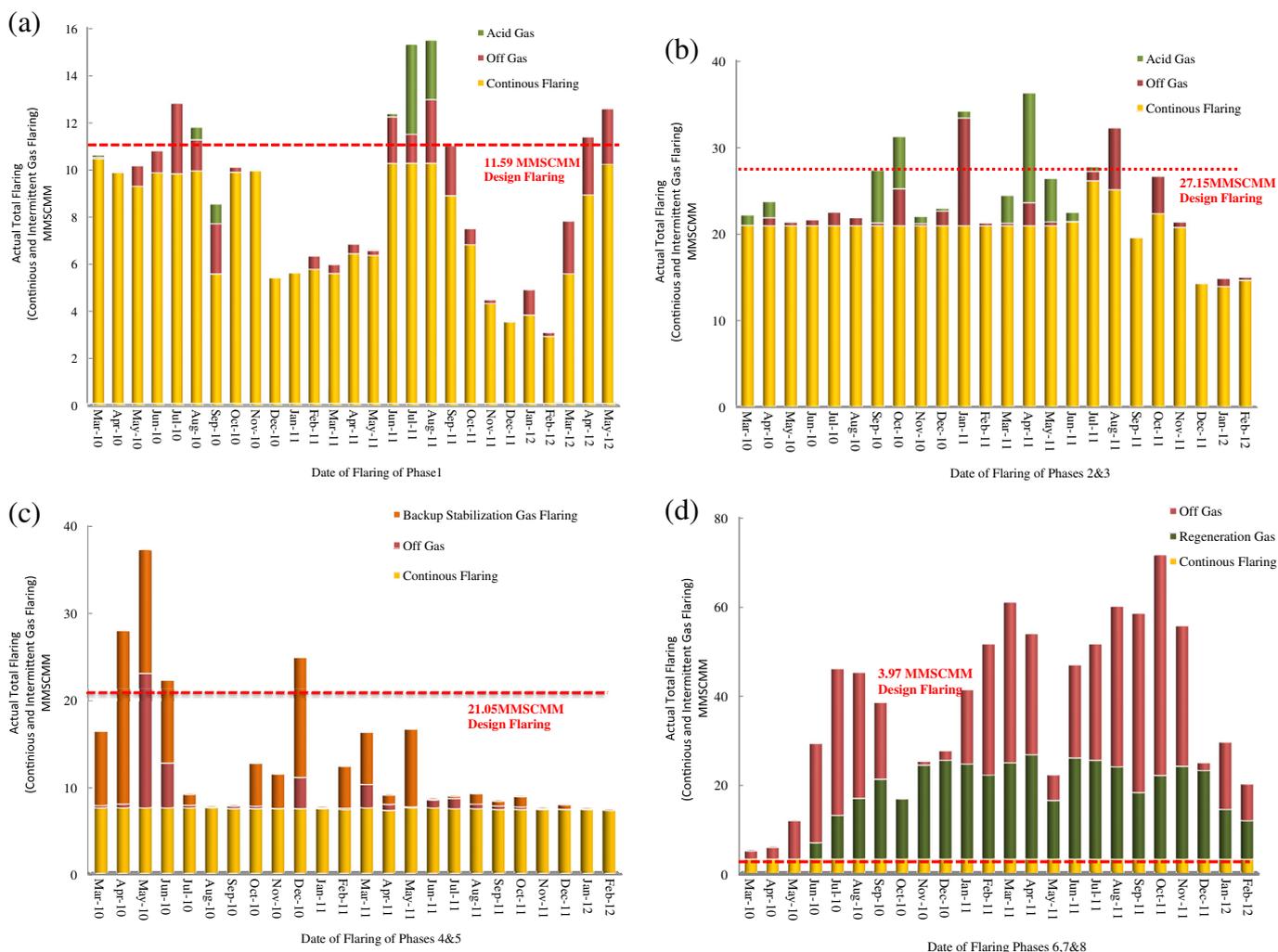


Fig. 6. Main Gas Flaring Sources of, (a) Phase 1, (b) Phases 2 and 3, (c) Phases 4 and 5, (d) Phases 6, 7 and 8.

mercaptan which are present in the MRU feed gas stream. When a dryer is mercaptan saturated, it is taken off adsorption mode and is regenerated to remove the residual impurities. A slipstream of the clean sweet gas is used as regeneration gas. The regeneration gas

flow rate is set to $2 \times 10,000 \text{ nm}^3/\text{has}$ two MRU units are put in service simultaneously. In the normal situation two out of three boilers are put in service to supply steam to the users. In this case about $8000 \text{ nm}^3/\text{h}$ is used as a fuel gas in the boilers and about

Table 1

The continuous gas flaring sources in each gas processing plant.

Source		Design continuous flaring/actual continuous flaring		
		ton/h	MMSCFD ^a	MMSCMD
Phase 1	Continuous flaring from MRU unit	11.95/7.28	12.63/7.86	0.36/0.22
	Continuous flaring from flash gas (FG)	0.00/0.00	0.00/0.00	0.00/0.00
	Continuous flaring from dehydration unit	0.400/0.400	0.350/0.350	0.01/0.01
	Flare (sweeping-purge-assist-pilot gas)	0.421/0.270	0.454/0.291	0.013/0.008
	Total	12.62/7.95	13.43/8.5	0.380/0.241
Phases 2 and 3	Continuous flaring from dehydration unit	3.69/3.73	3.98/4.03	0.11/0.11
	Flare (sweeping-purge-assist-pilot gas)	25.40/7.80	27.42/8.42	0.78/0.24
	Total	29.09/11.53	31.40/12.45	0.89/0.35
Phases 4 and 5	Flash gas from gas sweetening	4.59/2.31	4.84/2.44	0.14/0.07
	Flash gas from C ₂ treating	0.55/0.13	0.35/0.09	0.01/0.003
	CO ₂ from C ₂ treating	10.48/2.98	5.08/1.44	0.14/0.08
	Flares with considering of assist FG	61.26/17.29	66.13/18.66	1.87/0.44
	Flares without considering of assist FG	11.87/3.35	14.00/3.95	0.40/0.095
	Total with considering of assist FG	76.88/22.71	76.40/22.63	2.16/0.59
	Total without considering of assist FG	27.49/8.77	29.67/7.92	0.69/0.25
Phases 6,7 and 8	Flare (sweeping-purge-assist-pilot gas)	4.12/3.74	4.45/4.04	0.13/0.11
	Total	4.12/3.74	4.45/4.04	0.13/0.11

^a Million Standard Cubic Feet per Day.

Table 2
Flare vendor's information for Phases 2 and 3.

	Description	HP	MP	LP	
General	Flow rate max/norm/min	1313.5/500/200 MMSCFD	Max: 457,800 kg/h	Max: 40,439 kg/h	
	Mw	22.2/20.5/19.08	50.9	18.2	
	Gas temperature C	-17/-11.5	41	107.6	
	Pressure	13.087 psig	7.219 psig	0.378 psig	
	Min purge rate	130.8 Nm ³ /h	27 Nm ³ /h	2.6 Nm ³ /h	
	Assist gas		15,000 kg/h	8500 kg	
	Exit velocity	333/284/121 m/s	0.59 mach	216 fps (0.14 mach)	
	Press drop	3.1/0.7/0.1 bar	0.7 bar (total system)	0.035 bar (in stack)	
	TIP	Tip type	Low radiation, sonic	Pipe flare	Pipe flare
		Tip Model	Single nozzle HV flare tip	PF-30GA	PF-24GA
Vendor		AGRA	GBA	GBA	
Tip D		2198 mm	1) Flare size: 30 2) width :1.4 m	Flare size: 24	
Tip L		3500 mm	3500 mm	3000 mm	
Riser	Gas seal	Gas seal integral	Air lock seal	Air lock seal	
	Stack size	36"	30"	24"	
	Height	144.5 m	144.5 m	65 m	
	Design temp	-66/85	-46/140	2/150	
	Design press	7 barg	7 barg	7 barg	
	Press drop	0.9 bar	0.498 bar	0.026 bar	

12,000 nm³/h of MRU regeneration gas is sent to the flare as a continuous flow. To identify the behavior of the removed mercaptan during regeneration, a complete analysis was conducted and the peak of the impurities in the regeneration stream was detected versus time and temperature. The results show that the

content of mercaptan is low enough in the first 2 h heating time and in the final 8 h heating stage of the regenerated stream. This means half of the heating cycle time of the regeneration gas is allocated to boilers (the normal route) and the rest of the first heating stream which is equal to half of the heating time is allotted to the flash gas

Table 3
Sweeping gas flow rate in design and modified case in Phase 2.

Flare header	Unit	Flare header line size (inch)	A (m ²)	Q (m ³ /h) v = 219.45 (m/h)	Design mass flow rate (kg/h) P = 5.5 (barg) ρ = 4.3 (kg/m ³) MW = 17.03 (kg/kmol)	Modified mass flow rate (kg/h) P = 1.1 (barg) ρ = 4.3 (kg/m ³) MW = 17.03 (kg/kmol)
FA2	100/1	34	0.585	128.5	552.5	179.9
FA2	100/1	6	0.018	4.0	17.2	5.6
FS2	101/1	28	0.397	87.1	374.7	122.0
FS2	101/2	28	0.397	87.1	374.7	122.0
FS2	101/1	18	0.164	36.0	154.8	50.4
FS3	101/2	18	0.164	36.0	154.8	50.4
FA2	101/1	26	0.342	75.1	323.1	105.2
FA2	101/2	26	0.342	75.1	323.1	105.2
FA3	101/3	26	0.342	75.1	323.1	105.2
FA3	101/4	26	0.342	75.1	323.1	105.2
FA2	103/1	34	0.585	128.5	552.5	179.9
FS2	103/1	8	0.032	7.1	30.6	10.0
FB2	103/1	6	0.018	4.0	17.2	5.6
FB2	104/1	6	0.018	4.0	17.2	5.6
FB2	104/2	6	0.018	4.0	17.2	5.6
FC2	105/1	16	0.130	28.5	122.3	39.8
FC2	105/2	16	0.130	28.5	122.3	39.8
FT2	105/1	20	0.203	44.5	191.2	62.2
FT2	105/2	20	0.203	44.5	191.2	62.2
FB2	108/1,2	6	0.018	4.0	17.2	5.6
FS2	102	12	0.073	16.0	68.8	22.4
FS3	102	12	0.073	16.0	68.8	22.4
FB2	102	28	0.397	87.1	374.7	122.0
FA2	106	30	0.456	100.0	430.1	140.0
FA2/FA3	106	30	0.456	100.0	430.1	140.0
FS2/FS3	106	6	0.018	4.0	17.2	5.6
FS2	114/1	28	0.397	87.1	374.7	122.0
FC2/FC3	121	2	0.002	0.4	1.9	0.6
FC2	122	12	0.073	16.0	68.8	22.4
FS3	122	12	0.073	16.0	68.8	22.4
FB2	122	12	0.073	16.0	68.8	22.4
FT2/FT3	145	8	0.032	7.1	30.6	10.0
Total Fuel Gas Mass Flow Rate (kg/h)					6203	2019

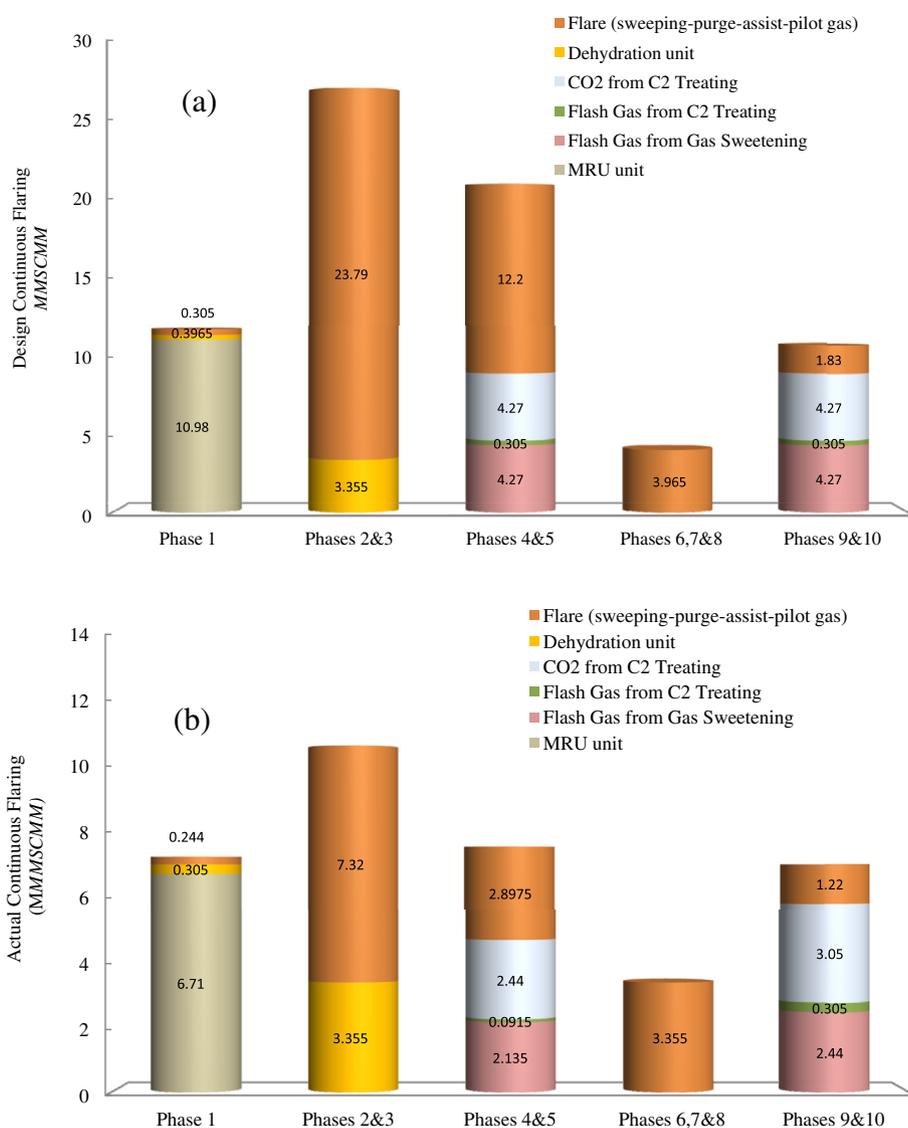


Fig. 7. Comparison of continuous gas flaring in Phases 1–10, (a) Design Flaring, (b) Actual Flaring.

compressor as a modified route. The recycling regeneration gas of the mercaptan removal unit in Phase 1 reduced 55% of the gas flaring in this gas processing plant.

3.1.4. Permanent solution of the regeneration gas in Phases 6, 7 and 8

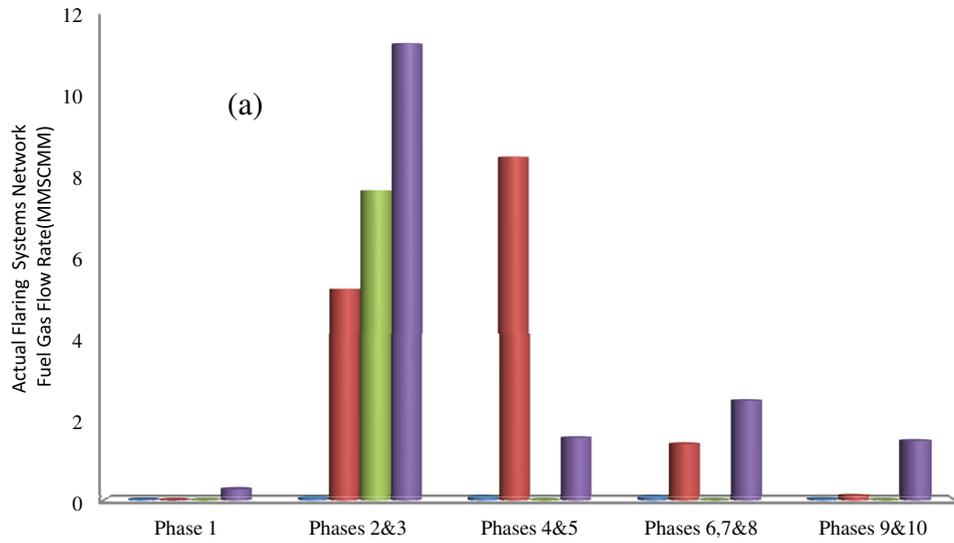
In Phases 6, 7 and 8, the regeneration gas of dehydration process is taken from the 56-inch sales gas pipeline of Phases 1, 2 and 3. The sales gas pressure of 90 barg is reduced by the pressure control valve provided outside the package to the required regeneration pressure (29.1 barg). The regeneration gas from the high pressure fuel gas header flows downward through the feed gas dryer and is heated in a regeneration gas heater. The hot gas then flows up through feed gas dryer. From the top of the feed gas dryer, the gas bearing water flows to a regeneration gas cooler. The regeneration gas cooler condenses much of the water adsorbed by the feed gas dryer. The regeneration gas leaving the drum is exported to the fuel gas system. The changing of some parameters was monitored during a complete cycle of the regeneration sequence of the dryer. The results showed that, there is a noticeable amount of H_2S and RSH in regeneration

gas. After investigation, it was found that RSH is adsorbed in the molecular sieve beds during adsorption time and released during the regeneration time. Mercaptans could be cracked at high temperatures to H_2S . As the regenerated gas has high H_2S content, corrosion could occur in the fuel gas network. Hence the regeneration gas is exported to flare rather than the fuel gas system. Therefore, in order to eliminate the regeneration gas flaring, some modification was made in this gas processing plant. The regeneration gas connection was a change from the inlet of the fuel gas network to the inlet of the export gas compressor. Fig. 9 shows the change of the inlet and outlet of the regeneration gas connection.

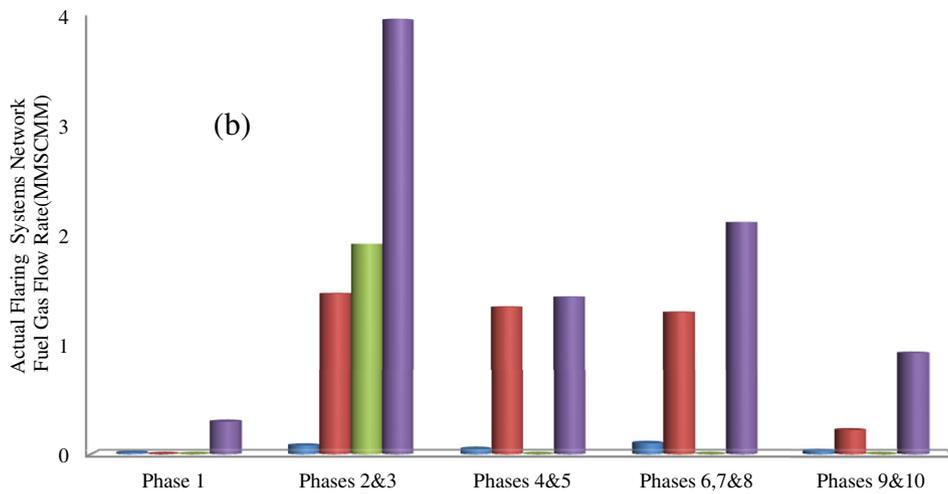
3.2. Alternative gas flaring

3.2.1. Off-gas flaring in Phase 1

Flash gas from the condensate stabilization process is compressed by the off-gas compressor and then passes to the Inlet of the gas sweetening process. When the feed of Phase 1 offshore gas processing plant is at a lower 50% capacity than the design rates, less gas is produced and the off-gas is vented to the flare system.



	Phase 1	Phases 2&3	Phases 4&5	Phases 6,7&8	Phases 9&10
Stack Pilot Gas (FG)	0.01	0.05	0.06	0.06	0.03
Stack Purge Gas (FG)	0.00	5.26	8.53	1.40	0.12
Stack Assist Gas	0.00	7.70	0.00	0.00	0.00
Sweeping Gas (FG)	0.29	11.34	1.55	2.48	1.49



	Phase 1	Phases 2&3	Phases 4&5	Phases 6,7&8	Phases 9&10
Stack Pilot Gas (FG)	0.01	0.07	0.04	0.09	0.03
Stack Purge Gas (FG)	0.00	1.47	1.35	1.30	0.22
Stack Assist Gas	0.00	1.92	0.00	0.00	0.00
Sweeping Gas (FG)	0.29	3.99	1.44	2.13	0.92

Fig. 8. The various types and amount of the fuel gas flaring network of the domestic gas processing plants, (a) Design Flaring, (b) Actual Flaring.

3.2.2. Backup stabilization gas flaring in Phase 4 and 5

High vapor pressure values of gas condensate are due to the pressure of dissolved volatile hydrocarbons called “light ends” such as methane, ethane, propane, butanes. To safely store condensate in tanks at atmospheric conditions or to transport condensate safely in pipelines at a defined operating pressure, the condensate vapor pressure value must be controlled or adjusted to meet pipeline, storage, or tanker Reid Vapor Pressure (RVP) specifications. The function of the stabilization unit is to remove the lightest components from the raw feed and to produce a liquid product. The

stabilization unit will give a stabilized condensate having a Reid Vapor Pressure (RVP) of 10 psia in summer and 12 psia in winter. As it is shown in Fig. 10 the raw condensate from the slug catchers is preheated (E-101A/B), then flashed (D-101) before going through a desalter (D-105). The condensate light components are then removed in the condensate stabilizer (C-101). The off-gas is compressed by (K-101) and returned to the HP separators and the stabilized condensate is cooled and sent to storage ready for export.

The debris build-up on the rebuilders’ tubes of the condensate stabilization column in Phases 4 and 5 leads to a decline in the

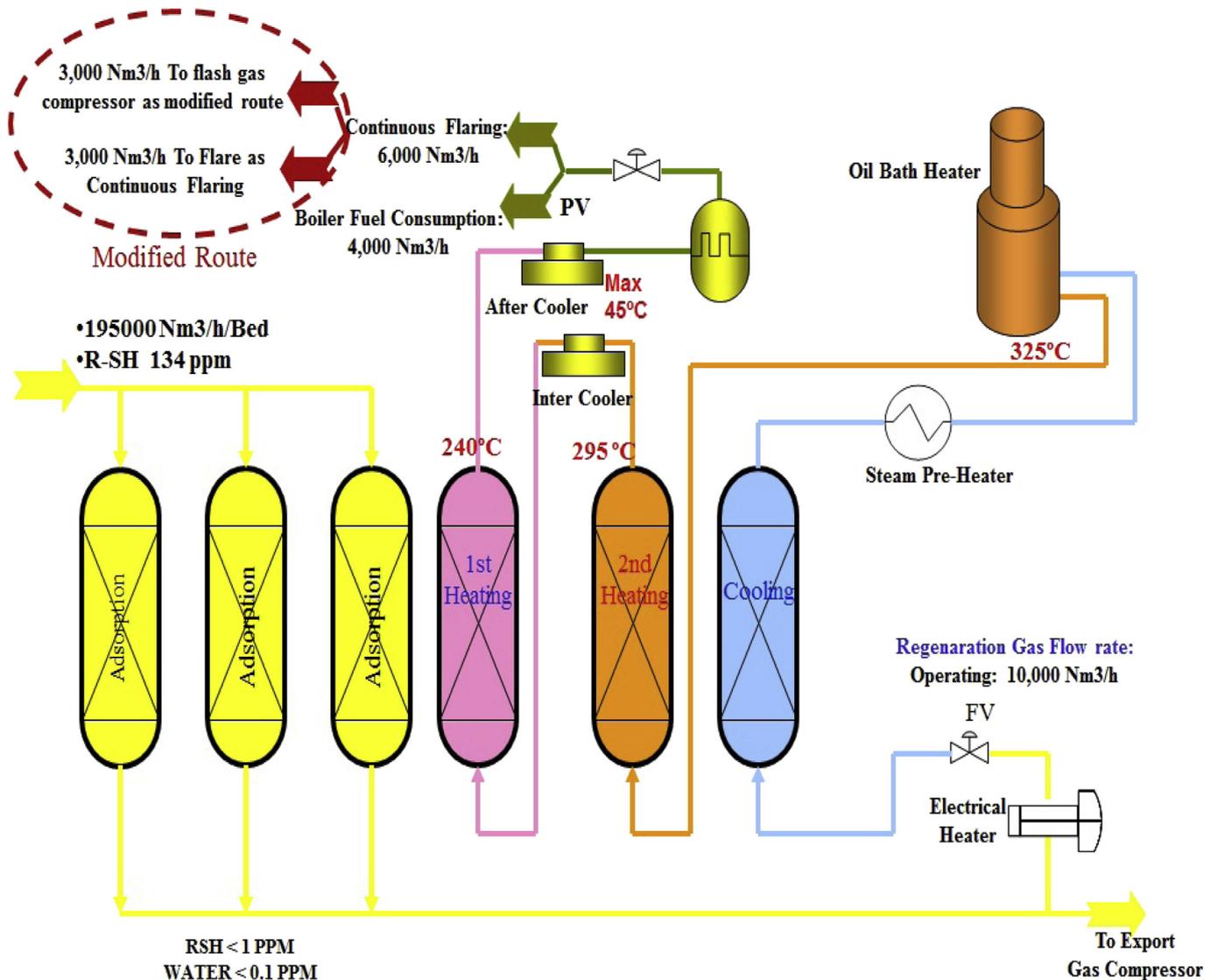


Fig. 9. The change of the inlet and outlet of regeneration gas connection in phases 6, 7 and 8.

reboiler duty and forces the periodic shut-down and removal of material, interrupting the normal processing operations which in turn contribute to flaring gases during maintenance procedure. The analysis of the debris with Environmental Scanning Electron Microscope (ESEM) method shows that the debris is composed of: Iron (Fe), Sulfur (S), Potassium (K), sodium (Na), calcium (Ca), Chlorine (Cl), Carbon (C) and oxygen (O). Therefore, the problem was solved by means of injections of a chemical de-emulsifier to the adequate removal of brine water from the gas condensate in the offshore separators in June 2011.

4. Results and discussion

The following conclusions are obtained from the analysis of the collected evidence:

- The major sources of gas flaring are the regeneration gas of the mercaptan removal unit in Phase 1, the sweeping consumption in the flare network in Phase 2 and 3, the backup stabilization gas flaring in Phases 4 and 5, off-gas and the regeneration gas in Phases 6, 7 and 8 and the off-gas in Phases 9 and 10.
- The calculation verification shows the overestimation of the sweeping gas flares network by the vendors. The Flare Net simulation results show that the back pressure of the flare network was overestimated to calculate the gas sweeping mass flow rate by the vendor in Phases 2 and 3. The adjustment of fuel gas consumption was made after the flare network back pressure calculation in Phases 2 and 3.
- In order to solve the excessive fuel gas network corrosion in Phases 6, 7 and 8 of the gas processing plant, a modification was made by re-routing the regeneration gas connection from the inlet of the fuel gas network to the inlet of the export gas compressor.
- The on-site evidence shows that the emergency shutdown and overhaul procedure during shutdown and start-up is the initiating cause of the gas flaring in each gas processing plant.
- A good production practices and the placement of treatment facility to remove emulsion, brine water and suspended solid is a very important and effective step to enhance the performance of gas processing plant and to reduce the need to repeated maintenance. Crystal modifier is as a wax dispersant and it prevent to agglomeration of heavy hydrocarbon. In order

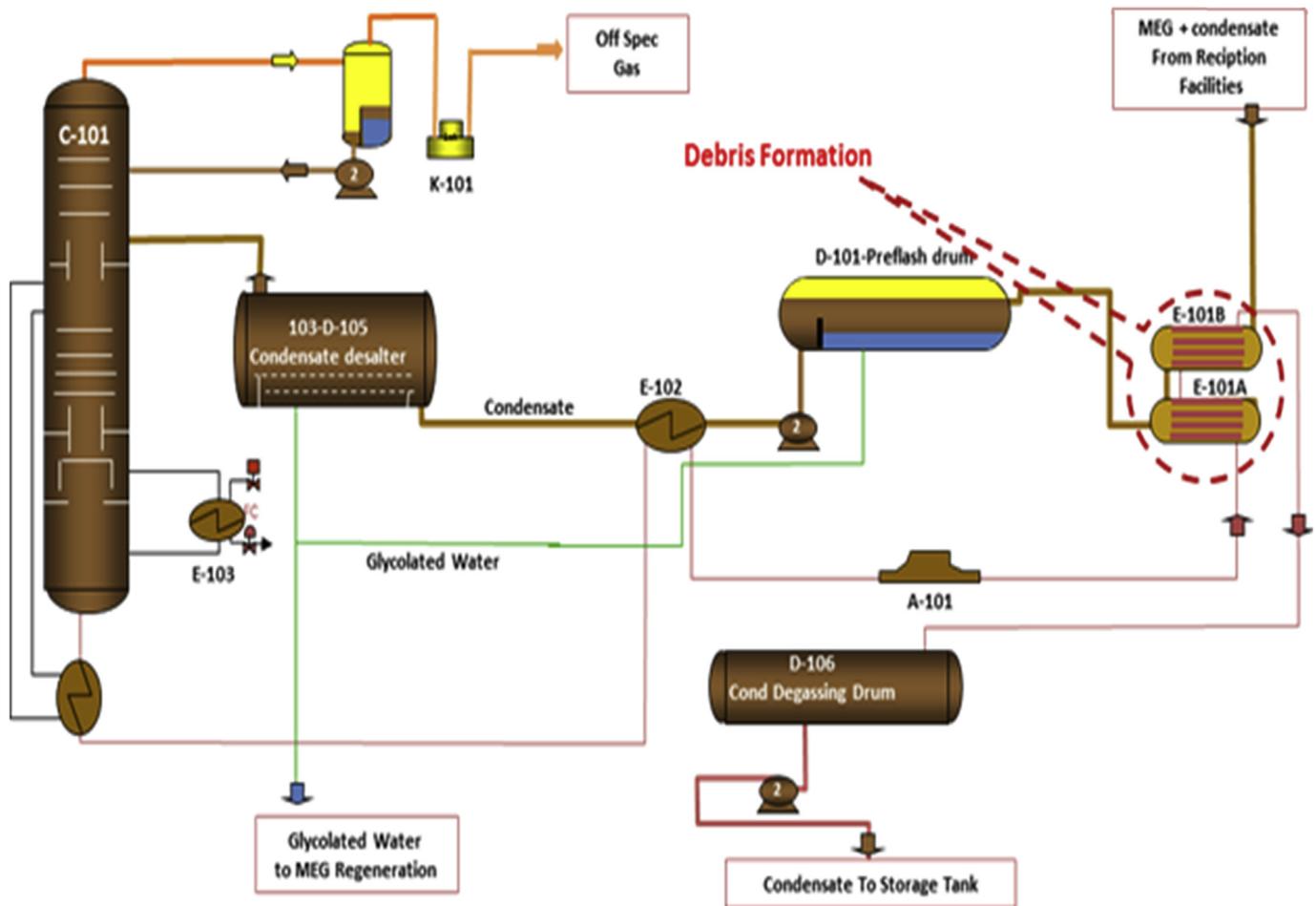


Fig. 10. Gas condensate stabilization unit and debris build-up on the reboilers tubes.

to address the debris build-up on the rebuilders' tubes of the condensate stabilization column in Phases 4 and 5, the injections of the chemical de-emulsifier were administered to remove brine water from the gas condensate.

5. Conclusion

The natural gas flaring reduction has high priority as it meets both environmental and economic efficiency objectives. Since a portion of produced natural gas of each gas plant has to be sent to the flare, a good flaring management can lead to the rational internal natural gas consumption. One of the basic and fundamental steps in this field of flaring management is the preparation of the flaring criterion for the existing gas plants and the setting of the flaring rate for new gas plants. An emissions inventory lists all the individual sources of each air pollutant in the gas processing plants of domestic Gas Company as well as their quantities. The results of the emissions inventory were used at the next step to identify the potential control options.

The adjustment of fuel gas consumption was conducted after the flare network back pressure has been calculated in Phase 2 and 3 by a Flare Net simulator. Excessive fuel gas network corrosion was inhibited in Phases 6, 7 and 8, by a modification performed in this gas processing plant. Chemical de-emulsifier injection allowed for removing the debris build-up on the rebuilders' tubes of the condensate stabilization column in Phases 4 and 5 in order to minimize the need of plant to repeated shutdown and

maintenance. The recycling regeneration gas of the mercaptan removal unit in Phase 1 reduced 55% of the gas flaring in this gas processing plant.

One of the largest sources of gas flaring and air pollutants in each gas processing plant is the unit shutdown. Therefore, the possibility study of recovering flare gas in the start-up and shut-down in the five gas processing plants should be done.

References

- Azam, F., Farooq, S., 2005. Agriculture and global warming: evapotranspiration as an important factor compared to CO₂. *Pakistan Journal of Biological Sciences* 8, 1630–1638.
- BP, 2010. BP Statistical Review of World Energy June 2010. Available at: www.bp.com/statisticalreview.
- Draft Iranian Ambient Air quality standard, May 1998. Environmental Regulations and Standards. prepared by the Bureau of Air pollution Investigation.
- Elvidge, C.D., Ziskin, D., Baugh, K.E., Tuttle, B.T., Ghosh, T., Pack, D.W., Erwin, E.H., Zhizhin, M., 2009. A fifteen year record of global natural gas flaring derived from satellite data. *Energies* 2, 595–622.
- IPS-E-SF-860, July 1994. Engineering Standard for Air Pollution Control.
- Johnson, M.R., Coderre, A.R., 2011. An analysis of flaring and venting activity in the Alberta upstream oil and gas industry. *Journal of the Air & Waste Management Association* 61 (2), 190–200.
- Johnson, M.R., Kostiuk, D.J., 2000. Efficiencies of low-momentum jet diffusion flames in crosswinds. *Combustion and Flame* 123 (1–2), 189–200.
- Johnson, M.R., Kostiuk, L.W., Spangelo, J.L., 2001a. A characterization of solution gas flaring in Alberta. *Journal of the Air & Waste Management Association* 51 (8), 1167–1177.
- Johnson, M.R., Wilson, D.J., Kostiuk, L.W., 2001b. A fuel stripping mechanism for wake-stabilized jet diffusion flames in crossflow. *Combustion Science and Technology* 169 (1), 155–174.

- McEwen, J.D.N., Johnson, M.R., 2012. Black carbon particulate matter emission factors for buoyancy driven associated gas flares. *Journal of Air & Waste Management Association* 62 (3), 307–321.
- Mochida, I., Koraia, Y., Shirahama, M., Kawano, S., Hada, T., Seo, Y., Yoshikawa, M., Yasutake, A., 2000. Removal of SO and NO over activated carbon fibers. *Carbon* 38, 227–239.
- Mukhopadhyay, N., Moretti, E.C., 1993. Current and potential future industrial practices for reducing and controlling volatile organic compounds. *AIChE*.
- National Air Pollutant Emissions Trends, 1900–1998. U.S. EPA and the States: Working Together for Cleaner Air, EPA-454/R-00-002, March 2000.
- Nordell, B., 2003. Thermal pollution causes global warming. *Journal of Global and Planetary Change* 38, 305–312.
- Nwankwo, C.N., Ogagarue, D.O., 2011. Effects of gas flaring on surface and ground waters in Delta State Nigeria. *Journal of Geology and Mining Research* 3 (5), 131–136.
- Nwaogu, L.A., Onyeze, G.O.C., 2010. Environmental impact of gas flaring on Ebocha-Egbema, Niger Delta, Nigerian. *Journal of Biochemistry and Molecular Biology* 25 (1), 25–30.
- Pohl, J.H., Lee, J., Payne, R., Tichenor, B.A., 1986. Combustion efficiency of flares. *Combustion Science and Technology* 50 (4–6), 217–231.
- Rahimpour, M.R., 2008. A two-stage catalyst bed concept for conversion of carbon dioxide into methanol. *Fuel Processing Technology* 89, 556–566.
- Rahimpour, M.R., Jokar, S.M., 2012. Feasibility of flare gas reformation to practical energy in Farashband gas refinery: no gas flaring. *Journal of Hazardous Materials* 209–210, 204–217.
- Rahimpour, M.R., Kashkooli, A.Z., 2004. Enhanced carbon dioxide removal by promoted hot potassium carbonate in a split-flow absorber. *Chemical Engineering and Processing: Process Intensification* 43, 857–865.
- Rahimpour, M.R., Mottaghi, H.R., 2009. Simultaneous removal of urea, ammonia, and carbon dioxide from industrial wastewater using a thermal hydrolyzer-separator loop. *Industrial & Engineering Chemistry Research* 48 (22), 10037–10046.
- Rahimpour, M.R., Jamshidnejad, Z., Jokar, S.M., Karimi, G., 2012. A comparative study of three different methods for flare gas recovery of Asalooey gas refinery. *Journal of Natural Gas Science and Engineering* 4, 17–28.
- Rittmeyer, Robert W., May 1991. Waste minimization-part 1: prepare an effective pollution prevention program. *Chemical Engineering Progress*, 56–62.
- Shu, Y., Lam, N.S.N., Reams, M., 2010. A new method for estimating carbon dioxide emissions from transportation at fine spatial scales. *Environmental Research Letters* 5, 041001–045301.
- Strosher, M.T., 2000. Characterization of emissions from diffusion flare systems. *Journal of the Air & Waste Management Association* 50 (10), 1723–1733.
- Xu, Q., Yang, X., Liu, C., Li, K., Lou, H.H., Gossage, J.L., 2009. Chemical plant flare minimization via plantwide dynamic simulation. *Industrial & Engineering Chemistry Research* 48, 3505–3512.
- Zadakbar, O., Vatani, A., Karimpour, K., 2008. Flare gas recovery in oil and gas refineries. *Oil & Gas Science and Technology – Revue d'IFP* 63, 705–711.
- Zahedi, G., Elkamel, A., Lohi, A., Jahanmiri, A., Rahimpour, M.R., 2005. Hybrid artificial neural network—first principle model formulation for the unsteady state simulation and analysis of a packed bed reactor for CO₂ hydrogenation to methanol. *Chemical Engineering Journal* 115, 113–120.