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Research Paper

Modification of the Associated Gas Compression Process for Flare Minimization

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ABSTRACT: *In this work a gas holder, which is a large gas storage reservoir, was used to modify an associated gas compression process to enable the reduction of gas flaring from natural gas compression facilities to take place. Investigation was made using live plant data obtained from a Floating Production, Storage and Offloading (FPSO) vessel offshore in the Gulf of Guinea into the major causes of gas flaring, despite the installation of Field Gas Compression (FGC) system. The gas holder was used as a source of gas compensation when the upstream gas flow fell below a set level according to the compressor operating parameters. The flow from the gas holder was calculated using the Fanno flow model. Simulation of the process was carried out to observe the compression process with fluctuations in upstream associated gas (AG) flow. Amongst the plant process failures identified were, namely, temperature, pressure, flow and level. The fluctuations in upstream AG flow stood out as the main cause of frequent plant trips and surge. The simulation results obtained showed a significant improvement in the gas compression process. Gas flaring during periods when the upstream gas flow was less than the minimum feed of 25mmscf/d flow required by the compressor station was shown to be avoided, improving productivity and compressor operating integrity.*

KEYWORDS: *Flaring, compressors, anti-surge control, gasholder, associated gas, gas compression*

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I. INTRODUCTION

Gas flaring is a major source of atmospheric emissions [1]. Whereas the major reason why gas is flared is to ensure that gases emitted to the atmosphere are combusted so as not to form combustible envelope in the environment and prevent accumulation of hazardous atmosphere around us, it subsequently presents its own hydra-headed problems [1].

Gas flaring is the controlled burning of natural gas and a common practice in oil/gas exploration, production and processing operations [2]. Gas flaring poses a serious threat to the environment. This problem can take the form of respiratory disorder in humans, corrosion of metals, attack on structures made of plastic or leathers, destruction of soil and vegetation, thermal pollution and its attendant negative impact on aquatic life. An International Oil Company (IOC) in 2000 conceived and implemented the gas re-injection mechanism whereby gas hitherto being flared are piped and re-injected to the reservoir. The east area project, off the shores of Qua Iboe River, which was commissioned in 2002, has the capacity to re-inject about 40mmscf/d of gas back to the oil and gas reservoir to maintain reservoir pressure. This mechanism, though a very expensive technology was able to drop the potential flare volume of 80mmscf/d to 20mmscf/d. The limitation of this laudable achievement, however, is that there is a limit to the pressure and volume of gas that the reservoir can take. This, when compared with the volume of associated gas produced from the oilfield, is still a far cry given the target daily flare volume of ≤1mmscf/d. Shell Nigeria's Cawthorne Channel Associated Gas Compression Project (CCAGP) started in 2003 and commissioned in 2006 was another major milestone achieved in terms of gas flare reduction. This incorporates three 50 mmscf/d capacity gas compressors in a gigantic Associated gas plant to receive, scrub, compress and dehydrate for export, up to 150 mmscf/d of Associated gas from three oil flow stations. This AG compression technique is able to keep the flare volume below the target 1 mmscf/d only when the plants are fully up. For period of plant trips, all the Associated gas received from the oil flow stations, which in most cases are in excess of 100 mscf/d are compulsorily flared. Considering that the compression plant up-time was less than 50% due to frequent trips and shutdowns, the need for optimization of the compression process becomes inevitable. Another major challenge to the achievement of reduced flaring by this means is the problem of minimum feed. Each of three AG compressors is fed from a different flow station and need at least

25mmscf/d flow as a minimum to load. A situation where one or more compressors are shutdown on insufficient feed arises as the feeder flow station cannot guarantee a steady minimum supply, due to its individual challenges ranging from the trip of its producing wells or entire flow station trips.

Surge can be termed the operating point at which the compressor peak head capability and minimum flow limit are reached. Under normal conditions, the compressor operates to the right of the surge line. However, as fluctuations in flow rate occur, or under startup/emergency shutdown, the operating point will move towards the surge line because flow is reduced [3]. Surge can cause damage to the mechanical parts of the compressor. When operating in a surge condition, the compressor discharge temperature increases significantly and the compressor experiences erratic and severe vibration levels that can cause mechanical damage—particularly to the internal seals. The most obvious way to bring the compressor out of surge is to increase flow [4]. Anti-surge control schemes rely on logic operations using control lines to trigger the opening of valves in order to recycle or blow the compressed gas to the atmosphere. The major disadvantage of this approach is the mechanical energy delivered to the recycled gas is partially wasted [5]. The basic elements of a compressor surge control system are the flow measurement (typically on the suction side of the compressor), pressure measurement, discharge check valve, recycle valve and its actuation system, and surge control system controller [3].

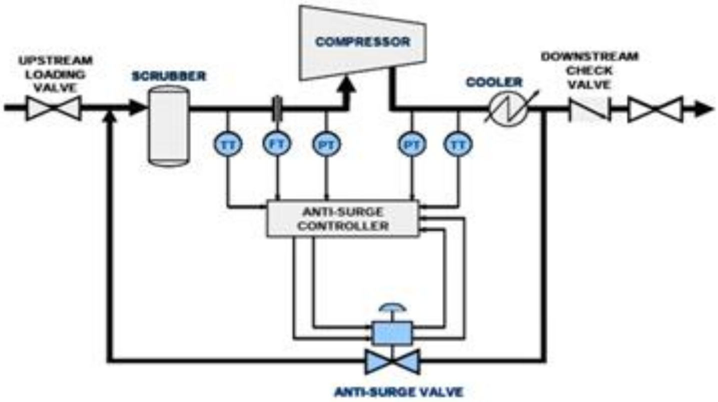

Figure 1. Typical compressor control system layout with single recycle valve (Source:[6])

A gas holder (commonly known as a gas holder) is a large container in which natural gas or town gas is stored near atmospheric pressure at ambient temperatures [7]. The gas holder also act as a regulator between production rates and the more erratic consumption rates, and provide the pressure for the distribution [8].

In this work, a gas holder is proposed to be used for flow compensation of gas during fluctuations in upstream AG flow, and during periods when the upstream flow is below the minimum feed flow required by the Compressor Station.

II. METHODOLOGY

The summary of the process failures obtained from the raw plant data is given in Table 1 below:

Table 1: Summary of raw plant data showing the occurrences of process failures over a 12-month period

Process Failure	No. of Occurrences	Vol. of Gas Flared (mmscf)	Fine Incurred ($)
Flow	11	170.306	596,071
Temperature	11	290.366	1,016,281
Pressure	18	286.380	1,002,330
Compressor Vibration	4	160.006	560,021
Total	44	907.058	3,174,703

Figure 2 shows the number of occurrences of the process failures in the different stages of the FGC trains. It is observed from the data obtained that most of the process failures occurred in the first stage.

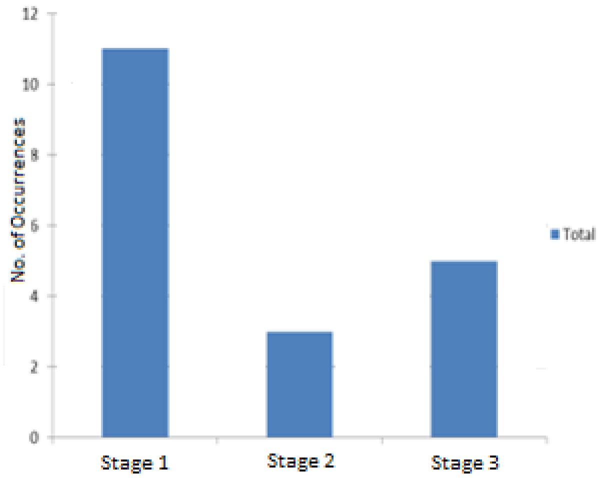

Figure 2: Occurrences of Process Failures in each of the stages of the three FGCs

2.1 DEVELOPMENT OF GAS HOLDER COMPENSATION MODEL

The main function of the gas holder will be to compensate the upstream AG flow when it goes below a set point (25mmscf/d) which is the minimum flow required for exporting gas. The control system of the gas holder compensation model is shown in Figure 3. The gas holder Control system gets its flow reading from the first stage anti-surge controller, and implements the compensation algorithm. The discharge pipe of the gas holder is connected to the upstream of the first stage suction scrubber, the same way as the anti-surge recycle line. The gas holder has three valves: the load valve; the filling valve; and the discharge valve.

When the gas holder is empty, the upstream loading/check valve is closed to direct the flow into to the filling valve which will be open. The gas holder discharge valve is closed to prevent flow into the suction scrubber, while the loading valve in opened to allow flow into the gas holder. If the gas holder was initially compensating gas, the compressor is first shut down before the refilling process of the gas holder.

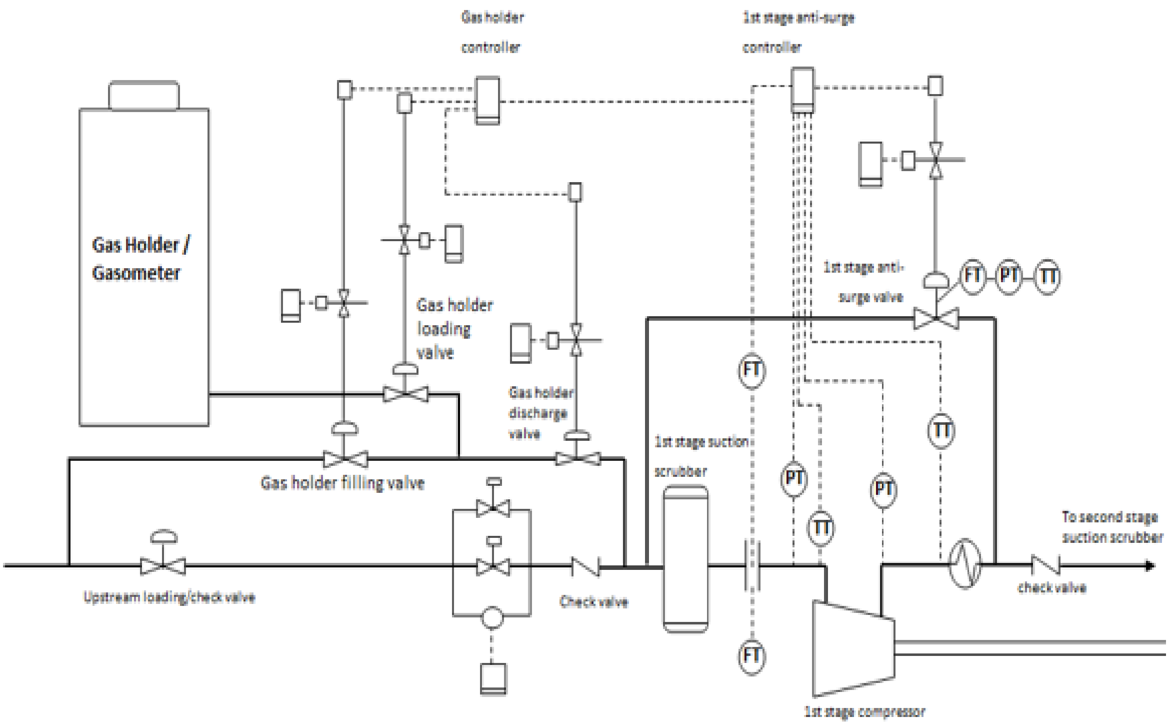

Figure 3: Developed Gas Holder Compensation Process model

After the gas holder is refilled, the compressors are brought back online. However, the refilling process takes place only when the upstream flow is not up to 25mmscf/d, given the consumer demand. If the flow is sufficient for export, the gas is channeled directly to the compressor train regardless of whether the gas holder is empty or not.

The gas holder compensates for flow by closing the filling valve to prevent back-flow of gas, and opening the loading and discharge valves. The valve positions are a function of the calculated flow compensation needed; large flow compensation means larger valve positions. The maximum flow compensation from the gas holder is set at 25mmscf/d because this is the minimum flow through the compressor that is required for exporting gas to the consumers (see Table 2). The gas holder supplies this maximum flow when the upstream AG flow drops down to zero.

	Stages		
Parameters	**1st Stage**	**2nd Stage**	**3rd Stage**
Compressor Speed (rpm)	13,326	13,326	13,326
Suction Pressure P_1 (barg)	10.4	28.2	69.2
Discharge Pressure P_2 (barg)	29.2	70.2	165.6
Suction Temperature T_1 (˚C)	48.6	48.9	48.9
Discharge Temperature T_2 (˚C)	124	126	126
Max. Flow Rate (mmscf/d)	56.7	54.2	52.1
Minimum Flow Rate (mmscf/d)	25	25	25
Turn-down Ratio (mmscf/d)	20	20	20

Table 2: Compressor Operating Parameters

2.2 DESIGN CONSIDERATIONS

Most gas holders have a capacity of 50,000m^3 (1.8mmscf) of gas storage. The diameter is usually 60m [7]. The largest ever built gas holder had a storage capacity of 20mmscf [9].

The capacity of the gas holder for four lifts (1.5mmscf – 4mmscf) is given by Equation 1 [10].

$$\frac{3.14\,D_1^2}{4} \times H_1 + \frac{3.14\,D_2^2}{4}(H_2 - h) + \frac{3.14\,D_3^2}{4}(H_3 - h) + \frac{3.14\,D_4^2}{4}(H_4 - h - 10'') \qquad (1)$$

(The value 10" which is subtracted from the height of the outer section represents approximately the pressure thrown by four lift holders).

The gas holder capacity assumed in this work is 1.8mmscf, which is the typical gas holder capacity.

For the determination of the rate of flow, we use Equation 2 [11]

$$Q = \frac{V}{t} \qquad (2)$$

$\therefore$ *rate of change of flow, r, with respect to time t is given as:*

$$\frac{\delta Q}{\delta t} = \frac{d^2V}{dt^2} = r = \frac{Q_1 - Q_2}{t} \qquad (Q_1 > Q_2)$$

$$\therefore\ Q_2 = Q_1 - rt \qquad (3)$$

Flow from the gas holder, Q_g, needed for compensation at time t

$$Q_g = 25 - Q_2 \qquad (4)$$

The resulting flow through the compressor will be the sum of the flow from the gas holder and the upstream flow

$$Q_{comp} = Q_2 + Q_g \qquad (5)$$

Equation 6 gives the volume of gas left in the gas holder, V_g, at time t.

$$V_g = (V_{t-1} \times 1000000) - (Q_g \times 11.574) \qquad (6)$$

Rearranging Equation 2, we get the time needed, in hours, required to refill an empty gas holder

$$t_{refill} = \frac{1800000}{(11.574 * Q_u * 3600)} \tag{7}$$

Where,
D_1 = Diameter in feet of inner section
D_2 = Diameter in feet of second section
D_3 = Diameter in feet of third section
D_4 = Diameter in feet of fourth section
H_1 = Height in feet of inner section
H_2 = Height in feet of second section
H_3 = Height in feet of third section
H_4 = Height in feet of fourth section
h = height of cup or grip which will be the same for all cups or grips of a given holder
Q = Volumetric flow
Q_1 = initial flow before fluctuation
Q_2 = final flow after fluctuation
r = rate of change of flow during flow fluctuation/decrease
t = time
V = volume

2.3 GAS FLOW FROM GAS HOLDER USING FANNO FLOW MODEL

The mass flow rate from a gas tank is dependent on the tank pressure and temperature, pipe length and diameter, minor losses, discharge pressure, and gas properties [12]. We model the flow from the gas holder to the suction pipe of the 1st stage suction scrubber using the Fanno flow. Fanno flow assumes that the pipe is adiabatic [13].

Gas specific gravity[13].

$$S = \frac{M_w}{M_{w,air}} \tag{8}$$

The molecular weight of the natural gas given in the compressor performance curve is 21.92

The molecular weight of air = 28.9647 [14]

Gas density is calculated using the density equation given in Equation 9 [13]:

$$\rho_t = \frac{P_t M_w}{R_u T_t} \tag{9}$$

We obtain the specific heat ratio, k, from the equation [15]:

$$k = \frac{c_p}{c_v} \tag{10}$$

The specific heat capacity, C_p, of natural gas is obtained from Figure 4 [16]

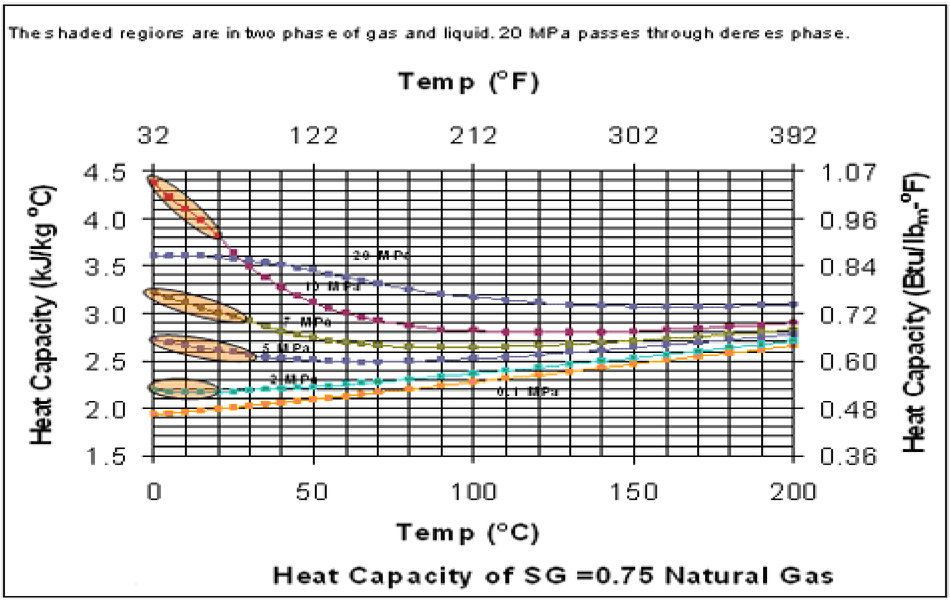

Figure 4: Graph showing the heat capacity of natural gas at different temperatures

At 48.6°C (temperature of upstream flow), the specific heat is approximately 2.6kJ/kg°C
According to [17],

$$C_p = C_v + R \tag{11}$$

The universal gas constant, R_u, is related to the individual gas constant, R, and the Molecular weight of the gas [14]:

$$R = {}^{R_u}/_{M_w} \tag{12}$$

Therefore,

$$C_v = C_p - R$$

Specific heat ratio,

$$k = \frac{C_p}{C_v}$$

The Resistance coefficient, K, is obtained from the table of typical K-values [18]:

$$K = f\frac{L}{D} \tag{13}$$

The standard (R/D = 1) K-value of a 90° Elbow curve fitting is given as 0.75

The Mach number, M, is estimated using Equation 14 [12]:

$$f\frac{L}{D} + \sum K_m = \frac{1-M^2}{KM^2} + \frac{k+1}{2k} + ln\left[\frac{\frac{k+1}{2}M^2}{1+\frac{k-1}{2}M^2}\right] \tag{14}$$

Equation 15 estimates the velocity of the flow from the gas tank [12]:

$$V = M\sqrt{\frac{kR_uT_t}{M_w}} \tag{15}$$

The volumetric flow rate can be estimated using Equation 16 [19]:

$$Q = \frac{\pi D^2}{4} V \tag{16}$$

Analysis carried out on the raw plant data in periods when the upstream AG flow was below the minimum flow required by the compressor station (25mmscf/d), showed that the average flow rate during such periods was 15mmscf/d. The compensation needed is therefore 10mmscf/d.
However, the flow supplied by the 16in. pipe was 4.06mmscf/d.

In order to get a flow of up to 10mmscf/d, the pipe diameter should be increased.
We also determine the diameter of pipe needed to get a maximum flow of 25mmscf/d (8.193m^3/s):
The gas holder valve flow coefficient, C_v, for critical flow can be calculated using Equation 17 [20]:

$$C_v = Q_g \sqrt{\frac{S \times T}{816 \times P_1}} \tag{17}$$

321.6K = 578.89^{o}R;   10.4barg = 150.84psi [21]

Therefore, the orifice size that should be used for the application of the gas holder valves with the above conditions is 0.062.

Where,

C_v = Valve flow coefficient
c = specific heat capacity
D = inner diameter of pipe
k = specific heat ratio
K = resistance coefficient
L = length of pipe
M = Mach number
M_w = Molecular weight of gas
P = Pressure
ρ = density of gas
Q = gas flow rate
R = Gas constant
S = Specific gravity
T = temperature
V = velocity of gas

III. GAS HOLDER COMPENSATION CONTROL ALGORITHM

The algorithm developed as shown in Figure 5 allows for control signals to be sent to the gas holder valves (filling, loading, and discharge valves). The values of the control signals are based on the measured flow of gas into the compressor derived from the model. The valve positions are provided by the control signals from the algorithm. When the flow through the compressor is below the flow specified for the minimum flow (25mmscf/d), the algorithm sends a control signal to the valves to open/close. The rate of change in the flow over time is used to adjust the amount of gain needed (i.e. a faster rate of change requires a higher gain signal from the gas holder controller) [3].

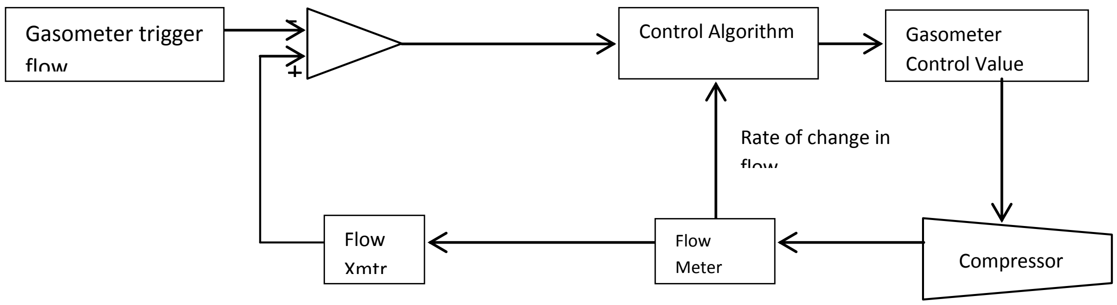

Figure 5: Gas holder block flow diagram

IV. PROCESS SIMULATION

The process simulation model is shown in Figure 6 below. The Input flow for the upstream AG flow is assumed to drop below the minimum of 25mmscf/d (Figure 7) to see the response from the anti-surge controller [22] and the gas holder controller.

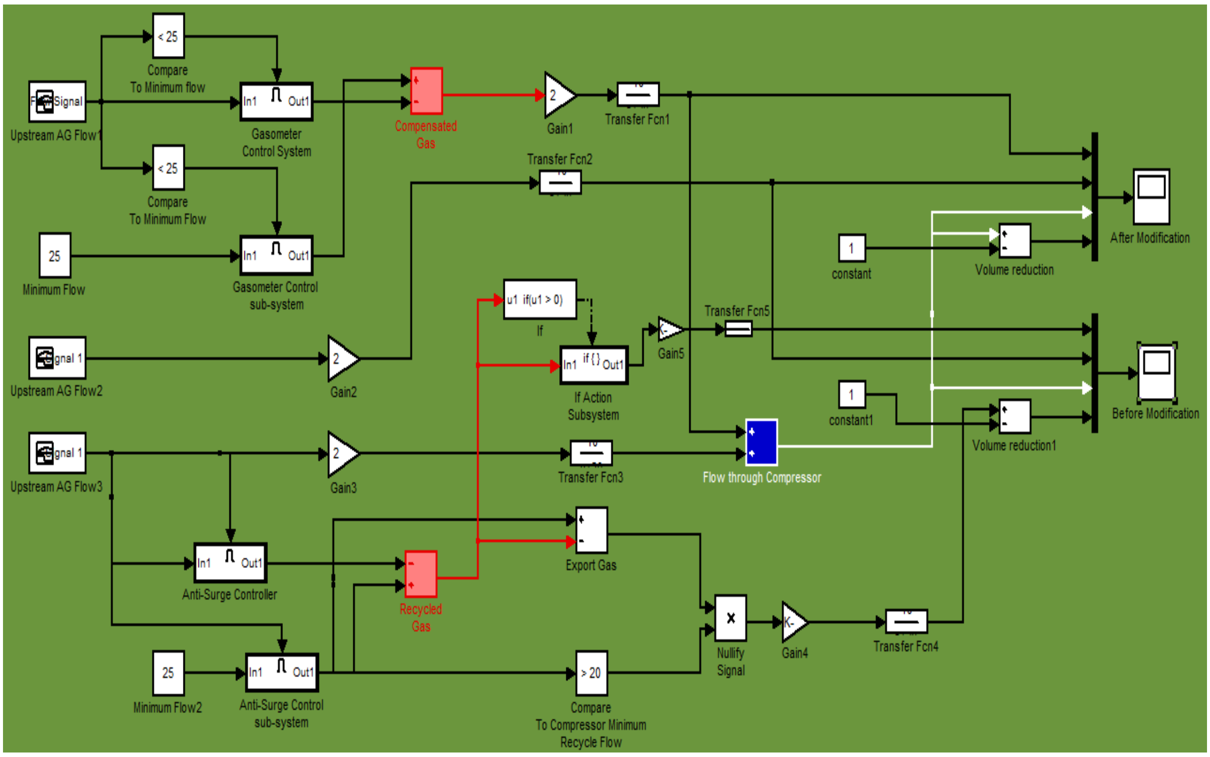

Figure 6: Simulink process flow sheet

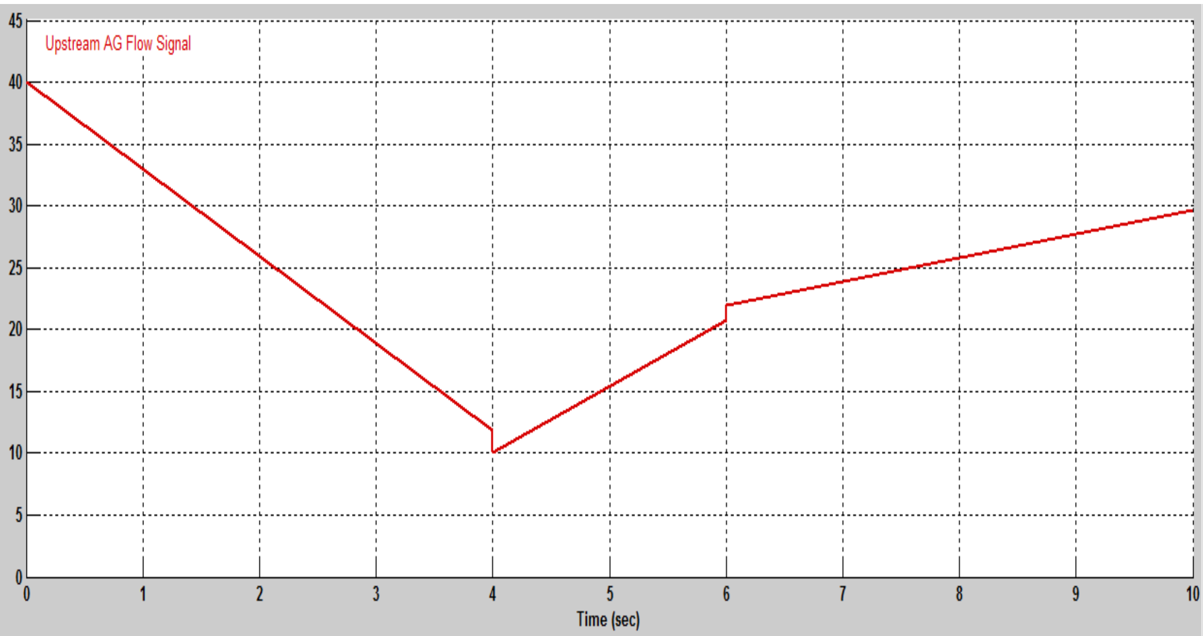

Figure 7: Upstream flow signal received by the gas holder controller

V. RESULTS AND DISCUSSION

The derived Design parameters required and used for the simulation of the process is shown in Table 3 below:

Table 3: Derived parameters for simulation

Design Parameter	Value
Valve flow coefficient	0.062
Specific heat, kJ/kg°C	2.6
Inner diameter of pipe, in	39.68
Specific heat ratio	1.17
Resistance coefficient	0.75
Mach number	0.86
Molecular weight of gas	21.92
Density of gas, Kg/m^3	8.53
Gas flow rate, mmscf/d	4.06
Gas constant	0.3793
Specific gravity	0.757
Temperature, °C	48.6
Velocity of gas, m/s	10.27

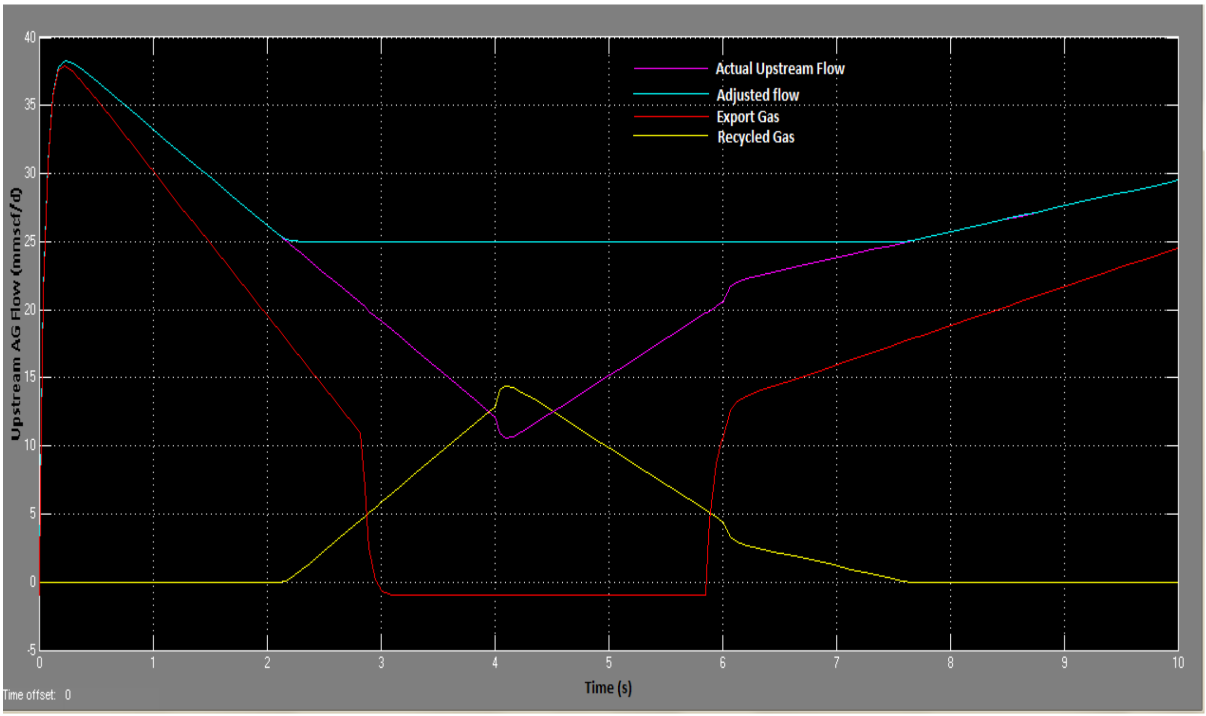

Figure 8: Graph showing simulation result before modification

In Figure 8, it was seen that when the upstream flow went below the turn-down ratio (20mmscf/d), the compressor was usually shut-down. This is because at such low flow levels, mechanical energy is wasted in recycling the gas and the compressor is at increased risk of entering into surge [5]. It is shown that as the flow decreases, the anti-surge maintains a minimum flow through the compressor, but the useful export gas is decreased (red line in Figure 8). This reduces the useful work done on the gas. The gas is flared when the compressor is shut-down due to low flow, reducing productivity substantially.

In Figure 9 below, it was seen that the gas flow through the compressor was maintained at 25mmscf/d during periods when the upstream AG flow went below 25mmscf/d, but the gas exported remains constant. This increases the productivity and useful work done on the gas. The gas in this case is not flared even when the upstream AG flow goes below the compressor turn-down ratio (25mmscf/d).

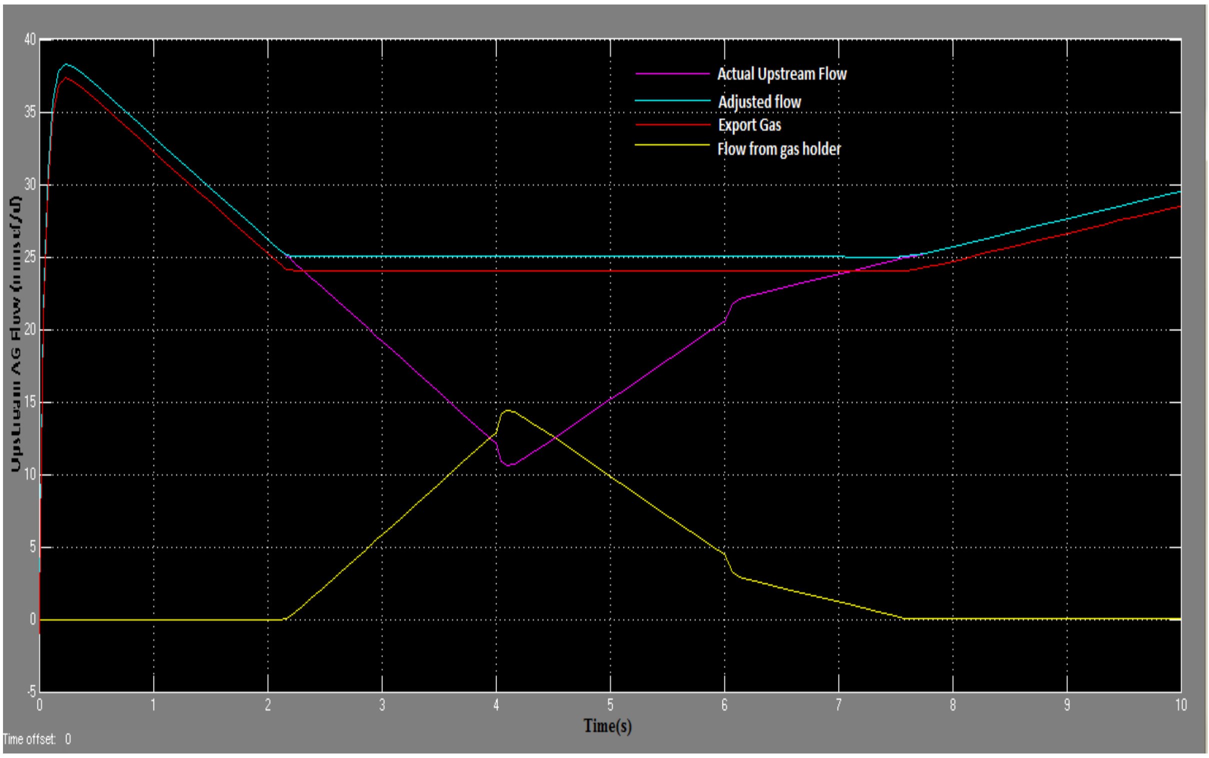

Figure 9: Graph showing simulation result after modification

With the installation of the gas holder, the start-up process of the compressors, in which the upstream flow must be up to 25mmscf/d, is improved. The gas need not be flared but compensated. Tables 4 and 5 summarizes the start-up process before and after modification of the process, respectively.

Table 4: Summary of start-up process of compressor with respect to upstream AG flow before modification

Upstream AG Flow (mmscf/d)	Compressor Status	Vol. of Gas Flared (mmscf/d)	Fine Incurred ($) ($3.5/1000scf)
1-24	Offline	1-24	3,500-84,000
25-56	Online	0	0

Table 5: Summary of start-up process of compressor with respect to upstream AG flow after modification

Upstream AG Flow (mmscf/d)	Compressor Status	Vol. of Gas Flared (mmscf/d)	Fine Incurred ($) ($3.5/1000scf)
1-24	Online	0	0
25-56	Online	0	0

VI. CONCLUSION

Gas holders can be used for the compensation of gas during periods of low flow (< 25mmscf/d). The gas holders should be located close to the compressors for fast compensation of gas in the steady state process. The anti-surge system will still remain, and during periods when the recycle valve is open the gas compensation from the gas holder quickly brings the compressor out of recycle mode, thus, improving surge prevention in the gas compression process.

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