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Research Article

Assessment of Operation and Catastrophic Risks of Transport Gasifier Pilot Plant

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Abstract: The assessment of operating failures and catastrophic risks of high temperature and high pressure circulating fluidized bed transport gasifier (CFB-TG) is presented. The safety analysis is based on the guide words set of a typical HAZOP study. CFB-TG pilot plant consisted of coal feeding arrangement, gasification column (riser), a dis-engager, a cyclone and gas handling system (scrubber). Safety analysis supported by the guide word technique starts with the detail study of the process, breaking down the process flow diagram into three nodes (coal feeding system, gasification loop, gas cleaning & cooling). For each node, deviations by using guide words highlighted by the team members with subsequent causes, consequences and corresponding safeguards were tabulated in HAZOP work sheets. The operational failures and catastrophic risks include explosion, noise pollution, gas emissions, ignition of coal in the feed line, back flow of gases, and feed line blockage, syngas failure at the outlet of gasifier, L-valve blockage, air supply cut off, and high moisture content of the feed. Hence, this step by step examination of process by guide word technique led to the modification in P & ID like installation of low and high pressure alarms and switches, level and temperature indicators, alarm systems, non-return valves as preventive measures to avoid operational and catastrophic failure.

Keywords: Operational failure, transport bed, deviation, guide words, HAZOP

1. INTRODUCTION

Transport bed gasifier for coal gasification is becoming a popular technology as higher through puts and efficient mass and heat transfer rate can be achieved. The operation at high temperature and high pressure can be dangerous. The identification and assessment of various operating failure and catastrophic risks is essential. HAZOP is a standard technique to identify the possible risks and hazards of chemical process plant. It is used in various process industries e.g. petrochemical, refinery, gas paper, power processing, mineral, mining, dairy, pulp industry [1]. In fact, HAZOP is the focus of much research aimed at improving the safety of chemical plants that increasingly operate at high temperatures and pressures and encompasses more sophisticated processes [2-3]. A hazard and operability study when applied to gasifier is identified to be a suitable approach for identification of the highest risks [4].

The potential hazards during operation of transport bed gasifier are due to the toxic and explosive mixture of gases that are produced. The syngas gas and residues may cause the risks like explosion and fire. Human health risks like pollution, noise, poisoning, hot surfaces, danger of suffocation within the plant vicinity requires the assessment of risks independently and collectively. The potential occupational hazards in various unit operations of the gasification plant are summarized in Table 1 [5].

The work presented here is part of safety studies for a typical Transport bed gasifier pilot plant in Pakistan. In order to identify the deviations and subsequent causes and consequences the HAZOP approach of guide word technique was adopted.

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The high temperature and high pressure circulating fluidized transport gasifier (CFB-TG) operating at 1000 °C and 100 psig is located in an educational environment, so the HAZOP studies have gained further importance to ensure the safety of the community and students.

Table 1. Potential occupational health & safety hazards of coal gasification plant**.**

Unit Operation	Potential Effect
Coal handling and preparation	Coal dust, noise, fire
Coal feeding	Coal dust, noise, gaseous toxicants, blockage
Gasification operations	Coal dust, high pressure, hot raw gas, high pressure oxygen, high pressure steam, fire, noise, back fire, explosion
Gas cooling	High pressure, raw hot gas, hot gas liquor, heat stress, noise
Particle separation	Blockage of disengager, cyclone, back flow pipe (stand pipe), Loop seal blockage
Burner assembly & recycle	Leakage of syngas, pilot or main burner failure.

1.1 Process Description

The plant consisted of a coal feeding arrangement, gasification column (riser), a disengager and a cyclone to separate the solids and the synthesis gas. Solids, including ash and unburned/unpyrolysed material, are returned to the tubular gasification column through a return pipe (stand pipe). A specially designed loop seal and L-valve is used to regulate the flow of the recycle material. A fraction of this material is collected in an ash canister. The synthesis gas available is cleaned through a scrubber and cooled through a heat exchanger. The synthesis gas thus made available can be used for various applications including production of liquid fuels, firing in steam power plant for power generation etc. The P&ID of the pilot plant is given in Fig. 1. The brief operating procedure of the plant is given below:

- Fill the stand pipe with inert material (ash and sand) through the filling port FP1.
- Pressurize the gasifier with nitrogen to 100 psig with all valve closed except V5.
- Fill the hopper with the premixed feed of sorbent and coal with the valve V1 closed and pressurize it to 110 psig with all operating valves closed.
- Open valve V14, start pump P1 to stabilize the circulation rate in the scrubber.
- Open three way valve V20 to allow the flow rate of gas towards flare.
- Ignite the pilot burner APB1 to ignite any combustible gas when released through pipe from scrubber.
- Switch on the compressor B1 and heater H1 to supply the heated compressed air to the gasifier at 100 psig. The air is allowed to release slowly through V25, V26 to start the fluidization process in the gasifier.
- Open the rotary valve V1 and start driven motor of feeding system at low feeding rate to feed the gasifier and burn high pressure pilot burner HPB1 in gasifier to allow the stabilization in the temperature in the gasifier.
- Make sure that the hot gases via three way valve V20 should be released to flare to avoid the pressure built-up. Switch on the recycle syngas blower B-1 and adjust three way valve V20 to allow the recycle of the gasses from the flare line in a specified ratio to maintain pressure of 100 psig in the gasifier.
- For shutting down, close the valve V1 and switch off coal feeding motor M1 to stop the feeding supply. Close the valves V8, V9, V10, and V5 thereafter. Monitor the temperature of the gasifier as it declines to less than 300 ^{O}C. Switch off the air heater H1 and do not switch off the blower B1 until the whole system is cooled down to sufficiently low temperature. Keep blower B2 running. Purge the system with inert gas by opening valve V20 to atmosphere. Switched off the recycle gas blower B1 and water circulation pump P1.

2. HAZOP METHODOLOGY

HAZOP is a rigorous and highly disciplined procedure to identify the gaps in operability and process risks that account for safety. The success lies in strength of the methodology to follow system process flow diagram (PFD) and piping and

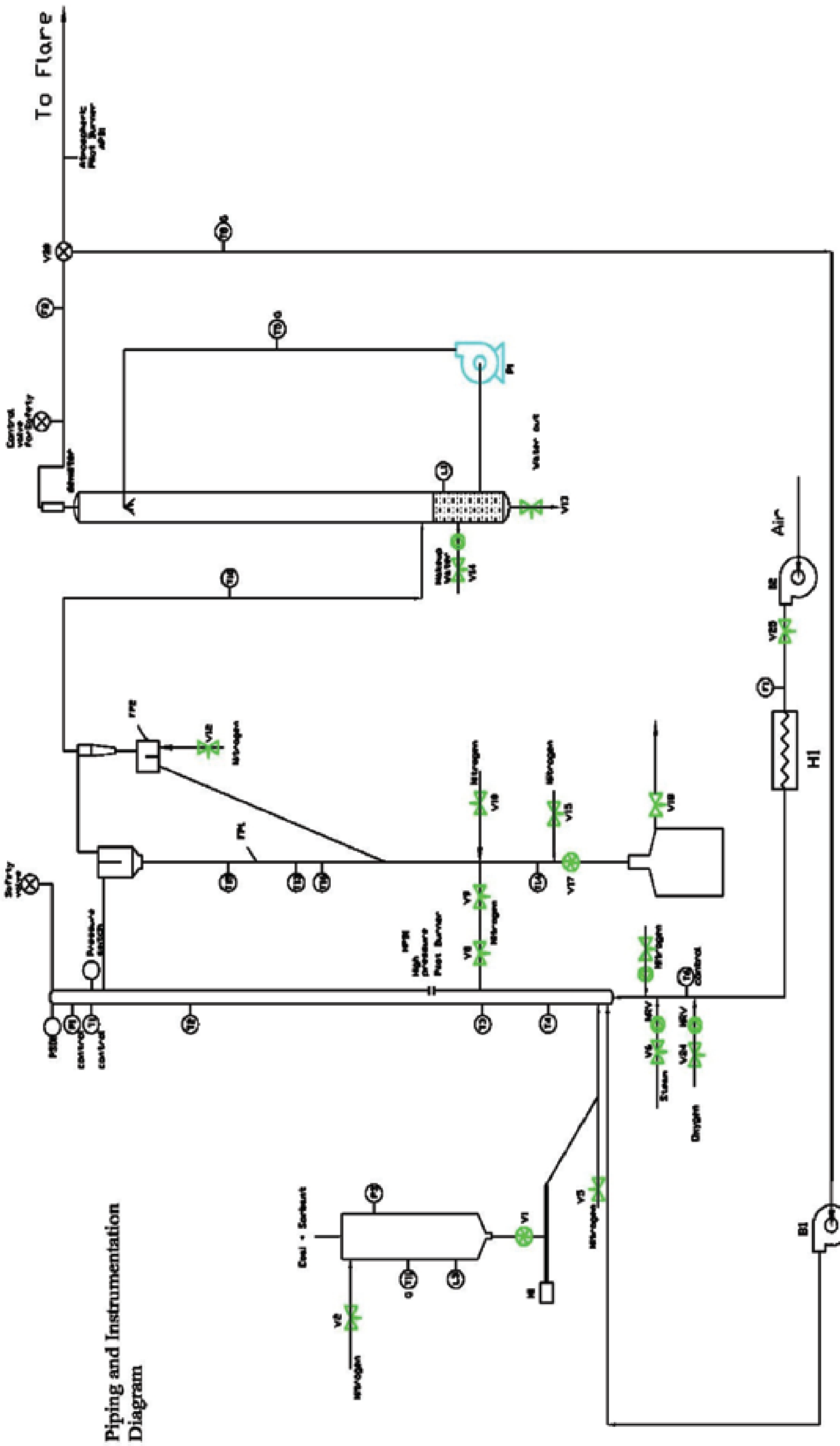

Fig. 1. P & ID of CFB-TG.

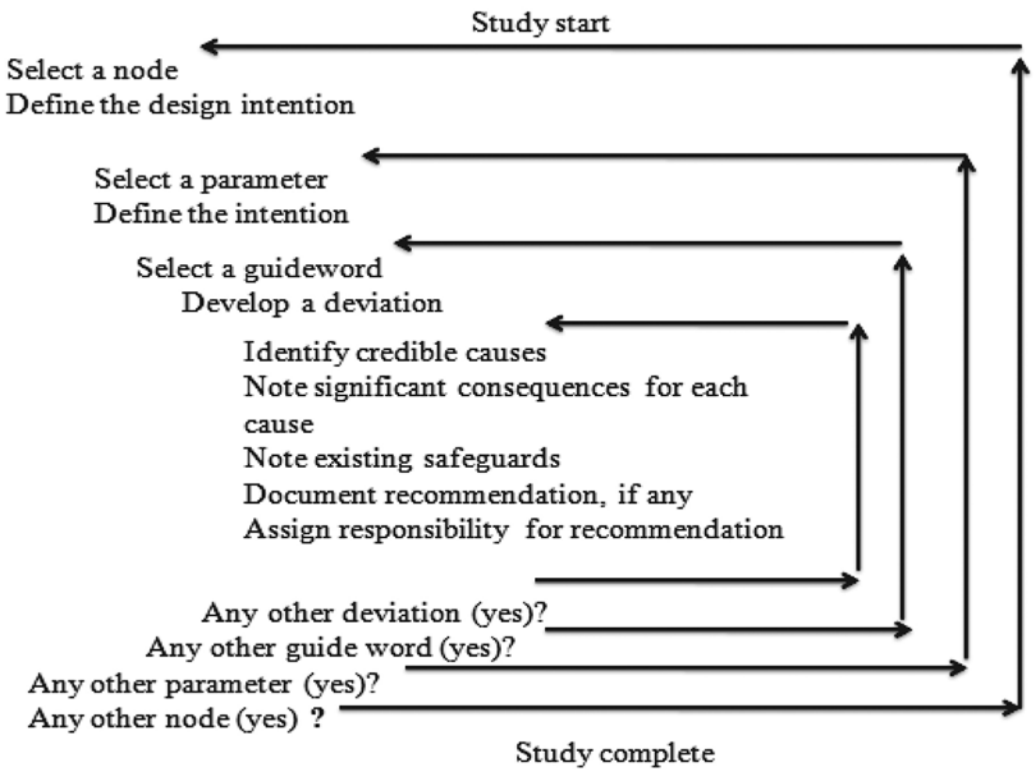

Fig. 2. HAZOP study chart.

instrumentation diagram (P & ID). As a first step the PFD is broken down into sections with defined boundaries to ensure the analysis of each section in the process [6-7]. Having determined the possible deviations, the next step is to identify the subsequent cause-consequences and safeguards to prevent, control or mitigate the hazardous situation. A set of "guide words" is used at the design stage. When the plant alterations or extensions are to be made on an existing facility a similar procedure is helpful. For this purpose, a team of five to eight people with diverse skills and experience of process, engineering discipline, management and plant operation etc is formed [3]. The examination procedure starts with the full description of the process which includes P & ID and systematically questions through guide words, every part of it to discover deviations and determine whether these deviations can give rise to hazards. The potential problems are then noted for remedial action. The immediate solution to the problem may not be obvious and could need further consideration either by a team member or perhaps a specialist. All decisions taken are to be recorded. The major steps involved in studying guide word technique for CFB-TG are shown in Fig. 2.

Table 2. Guide words used to identify risks/ operating problems.

Guide Words	Meaning	Comments
NO	Complete negation, e.g. of intention	No forward flow when there should be
HIGH	Quantitative increase	More of any relevant physical property than there should be (e.g. higher flow, temperature, pressure, viscosity, etc. also actions: heat and reaction).
LOW	Quantitative decrease	Less of….(as above)
AS WELL AS	Quantitative increase	All design and operating intentions are achieved together with some addition (e.g. Impurities, extra phase…)
PART OF	Quantitative decrease	Only some of intention are achieved, some are not
REVERSE	Opposite of intention	Reverse flow or chemical reaction (e.g. inject acid instead of alkali in pH control)
OTHER THAN	Complete substitute or miscellaneous	No part of original intention achieved, something quite different occurs.

Table 3 Example HAZOP work sheets for different Nodes.

Sheet No: 2/2 Date: 10-09-2009 Node Function: Gasifier
Node : 3 Parameter: Pressure Design Intent: Combustion of Coal

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	High	-Outlet line of vessel blocked -Excessive fuel -High Temperature	-Reverse flow -PSV operates and release gases in atmosphere -Reverse flow in L Valve	<1% <1%	-PSV installed High pressure alarm installed -Temp. Indicator installed	Inspection
2	Low	Feed line blocked	-Gasification slow down -Ash sucked in	<1 %		

Sheet No: 1/2 Date: 10-09-2009 Node Function: Supply of Coal and Sorbent
Node : 1 (Feed Hopper) Design Intent: Pressurized Operation (100 psig)
Parameter: Level of Coal (Quantity in feed hopper)

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	Low	-Withdrawal rate high	-feed hoppers get empty -vaccum created -fuel supply is interrupted	<5%	Level indicators	Level indication missing
2	High	Not relevant				
3	As well as	Not relevant				
4	Part of	Not relevant				

Sheet No: 2/2 Date: 10-09-2009 Node Function: Supply of Coal and Sorbent
Node : 1 (Feed Hopper) Design Intent: Pressurized operation (100 psig)
Parameter: Storage Pressure

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	Low	-N_2 Supply cut off -Leakage in vessel	- Reverse flow possible and may lead to explosion	<10% <1%	Low Pressure switch/alarm Inspection	Missing
2	High	-N_2 Supply valve failed open -Operator set high falsely	-Vessel may rupture -Excessive feed flow	< 1% <10%	High pressure alarm PSV protection	Missing

Sheet No: 1/3 Date: 10-09-2009 Node Function : Supply of Feed(Coal and Sorbent) to Gasifier
Node : 2(Feed Line) Design Intent: 3 gm/sec
Parameter: Flow Rate of Coal

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	Low/Less	-Syn gas failed Line plugged -No coal in feed hopper -Valve V1 or V2 stuck close Vessel. -Higher pressure in gasifier	- Gasification die out -Back flow gases may lead to explosion	<20% <10% <10% < 10% <20%	-Alarm - redundancy in valve -NRV-1 -NRV-2	Inspection
2	High	-N_2 Supply valve failed open -Operator set high falsely	-Vessel may rupture -Excessive feed flow	< 1% <10%	High pressure alarm PSV protection	Missing

Table 3 (Contd.)

Sheet No: 2/3 Date: 12-09-2009 Node Function : Supply of Feed(Coal +Sorbent) to Gasifier Design
Node: 2 (Feed Line) Parameter: Pressure Intent: 3 gm/sec

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	High	Line is plugged	- Line may leak or rupture -Nitrogen/Steam may cut off to gasifier	<1 %	Pressure gauge	
2	Low	-Compressor B01 fail -Nitrogen supply ends -Steam may exhaust				

Sheet No: 3/3 Date: 12-09-2009 Node Function : Supply of Feed (Coal +Sorbent)
Node : 2 Parameter: Temperature

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	Low	Irrelevant				
2	High	Conduction from gasifier Back flow of gases	-May ignite coal in feed line -May cause explosion -NRV may damage	<5 % <1%	Pressure monitoring and NRV is installed	
3	As Well					
4	Part of					

Sheet No: 1 Date: 10-09-2009 Node Function: Dis-engager
Node : 4 Parameter: Flow Rate of Gases Design Intent: Dust Removal

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	High	High pressure in gasifier	Dust separation efficiency drops. More flow in Loop seal leads to increase in circulation through L valve.	<1%	---------------------	
2	Low	Low pressure in gasifier	Dust separation efficiency drops. Reduced flow through Loop seal shall plug it and level of solids shall increase in J Leg.	<1 %	---------------------	

Sheet No: 1 Date: 10-09-2009 Node Function: Scrubber
Node : 6 Design Intent: Cooling of Syn. Gas

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	Leakage or rupture of tube/pipe	High pressure in pipe due to pipe blockage or clogging of filter in the outlet line	-Release of syn. Gas may caught fire in presence of ignition source - depressurize the upstream system	<1%	-Pressure monitoring - Regular inspection	------------
2	Failure of fan compressor	-power failure -motor burn out	No cooling results to hot gases may damage candle filter	<10 %	---------------------	

Sheet No: 1 Date: 10-09-2009 Node Function: Collect Ash
Node: 5 Design Intent: Remove Ash + Sand

Sr. No	Deviation	Causes	Consequence	Probability of occurrence	Safeguards	Remarks
1	High Temp.	Cooling water failure	-vessel may damage	<1%	------------	1
2	High Pressure	Air vent blocked	Hammering occurs	<1 %		

3. PROCESS IMPLEMENTATION

The systematic process implementation requires critical study of the plant. For the evaluation of credible unfavourable, and potentially hazards situations and subsequent consequences, process flow diagram (Fig. 2) was divided into following nodes: (1) Coal feeding system; (2) Gasification loop; and (3) Gas cleaning and cooling as per the requirement of the selected technique discussed in previous section. The guide words that are planned for the safety analysis are given in Table 2 [8].

Node 1

The portion of process flow diagram undertaken in this section was coal feeding system. Started from feed hopper the parameters that were observed to be investigated by expert team members were storage pressure and level of coal in the storage hopper. And it was reported that level indicator on hopper and high and low pressure switches and alarms on N_2 supply line were missing in the available P & ID. After documenting the recommendations, pressure and flow rate in the feed line were analyzed. The reported possible causes of the failure and hazards were coal supply failure, high pressure in the gasifier, feed line plugging & failure of compressor that may result in back flow of the gasses, rupture of vessel, excess feed flow, rupture or leakage of line and nitrogen cut off respectively. Next parameter that was selected for safety analysis was temperature in the feed supply line. As a result of the high temperature, ignition of coal might be possible in the feed line or it may cause explosion. To avoid this potential hazards and operational failures, installation of high pressure alarm in the feed line, NRV, pressure gauge and pressure monitoring were recommended.

Node 2

Gasifier (riser), disengager and cyclone separator were discussed in this node. The first unit selected for safety analysis was gasifier by taking composition and pressure into account. After step by step analysis through guide words, parameters selected for examination were high moisture content, high sulphur content, high and low pressure respectively with potential consequences of external heating requirement, longer time to achieve steady state, formation of sulphur dioxide, reverse flow of gases from riser and feed line blockage (with low pressure in gasifier). Flow rate of gases was only parameter while discussing disengager and cyclone separator. The potential causes of the deviation were high and low pressure in the gasifier which causes the operation failure like drop in dust separation efficiency, more flow in loop seal and reduced flow through the loop seal, respectively.

Node 3

While analyzing scrubber the deviations highlighted in this node were the leakage/rupture of tube, failure of fan compressor, high temperature and high pressure for the design intent of syngas cooling and ash removal repectively. The potential consequences of deviations observed were syngas release, ignition of coal, damaging of vessel and hammering, respectively.

The sample work sheets for different nodes is shown in Table 3.

3.1 Operational Failure

Node analysis of guide word technique has highlighted many operational failures like back flow of the gases from gasification unit to feed hopper because of the pressure difference, interruption of fuel supply because of no feed in the hopper, syngas failure at the outlet of gasifier (gasification die out), air supply failure to the gasifier, high temperature of the scrubbed gas at the out let of the scrubber because of cooling water failure. These are the operational failures that were highlighted in safety analysis of the CFB-TG and to prevent these failures and recommendations were suggested which have been discussed in this paper under the heading of safeguards and recommendations.

4. RECOMMENDATIONS

The guide word methodology was implemented on CFB-TG to investigate the operation and catastrophic risks and following recommendations are made:

1. A level indicator on feed hopper may be installed, which was missing in the available flow sheet. In the absence of it, if the withdrawal

rate of feed is high then vacuum may be created or supply of fuel may be interrupted.

2. To prevent reverse flow of gasses, explosion, rupture of vessel and excessive feed flow, install low and high pressure switch/alarm, PSV on feed hopper.
3. Install alarm, NRV, high pressure alarm, PSV and pressure gauge in the feed line. As sysngas failure, high pressure in the gasifier, no coal in feed hopper result in the back flow of gases, excessive feed flow, ignition of coal in feed line, vessel rupture and gasification reaction failure. For available P & ID, inspection of alarms, NRV was recommended and high pressure alarm and PSV was missing.
4. Provision of external heating in plant facility and addition of sorbent in the feed was also suggested as safeguards. Because longer time to achieve steady state, more external heating, formation of SO_2 and toxicant in ash are the results of high moisture and sulphur contents.
5. Regular pressure monitoring and inspection and cooling water flow rate regulation were also recommended for scrubber section of available plant facility to avoid pipe blockage, cooling water failure.

The above stated recommendations, modified as per outcomes of the subsequent detailed analysis, have been accommodated and considered in the process and instrumentation diagram. The changes with reference to alarms, regulators, safety valves and regular inspection have eliminated the serious causes of accidents, explosion and hazard to the plant personnel, the public or environment.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Colin, F. Adding failure effects to HAZOP. *IChemE Loss Prevention Bulletin* 211: 26-32 (2011).
2. Jordi, D., F. Vasilis, A.V. Juan, & A. Josep. Hazard and operability (HAZOP) analysis: A literature review. *Journal of Hazardous Materials* 173(1-3): 19-32 (2010).
3. Ramzan, N., F. Compart, & W. Witt. Methodology for the generation and evaluation of safety system alternatives based on extended HAZOP. *Process Safety Progress* 26(1): 35–42 (2007).
4. Raija, K., W. Nina, E. Annele, A. Toni, K. Sirkku, M. Jouko & H. Minna. Integrating future-oriented technology analysis and risk assessment methodologies. *Technological Forecasting & Social Change* 76: 1163-1176 (2009).
5. Ian, C. & R. Raghu. *Process Systems Risk Management*. Elsevier Academic Press, Sydney, Australia (2005).
6. Kletz, T.A. *Hazop and Hazan: Identifying and Assessing Process Industry Hazards*. Institution of Chemical Engineers, Rugby, Warwickshire CV 21 2HQ, UK (1992).
7. Elliott, D.M. & J.M. Owen. Critical examination in process design. *The Chemical Engineer* 233: 377-383 (1998).