World Largest Tangentially Fired Acid Gas Incinerator in LNG Plant: Startup and Operational Experiences

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ABSTRACT

Environment is fast becoming a major aspect of oil and gas industry alongside safety and production. With increasing plant capacity, tighter government and international regulation as well as increasing sensitivity and awareness of the public; meeting environmental limits has never been as important and challenging as what we are facing today. Demand for gas and specifically LNG has been steadily growing and is seeing its best growth since past years. Even though known for its clean combustion property, gas processing still has to deal with discharging harmful byproduct waste to the environment safely. In most LNG plant, due to the presence of CO_2, H_2S and BTX in the feed gas, continuous stream of acid gas from the process has to be discharge to atmosphere. The best way to do this safely and economically is through acid gas incineration. Malaysia's PETRONAS LNG complex in Bintulu, Sarawak, comprises of MLNG Satu (1983), MLNG Dua plants (1995) and MLNG Tiga (2003). With MLNG Tiga peak acid gas production of 5200 t/d, the designer of MLNG Tiga acid gas incinerator faced a challenge of building world largest acid gas incinerator. The paper is about the accomplishment of the new design and more importantly the lessons learnt from the startup and operational experience of the unit from process and process control point of view. A story of success with a lot to be learns for an even greater future success.

1 INTRODUCTION

1.1 PETRONAS LNG COMPLEX

Situated in a small town of Bintulu in the island of Borneo, Malaysia; Petronas LNG complex consist of 3 LNG plants namely Malaysia LNG (MLNG), Malaysia LNG Dua (MLNG Dua) and Malaysia LNG Tiga (MLNG Tiga). MLNG, which consist of 3 LNG trains was incorporated in 1978 and delivered its maiden cargo to Japan in January of 1983. Growing demand of LNG and vast reserve of natural gas from the central Luconia basin open ways for further establishment of MLNG Dua Train 4, 5 and 6 in 1994 and MLNG Tiga Train 7 and 8 in 2003. With the completion of MLNG Tiga, Petronas LNG complex became the world largest LNG plant in a single location with total capacity of 23 million tonne per annum. To date, Petronas LNG complex had successfully delivered more than 4000 cargoes of LNG to its buyers without a single failure. With impeccable delivery record and world's class safety achievement; Petronas LNG complex sets the industry standard.

1.2 PROCESS DESCRIPTION

The plant can be divided into 4 main sections, which are the upstream facilities, gas treating, liquefaction and storage/terminal. The upstream facilities receive gas via 125km pipeline from the sea in the Central Luconia basin and separate the condensate from the gas. The gas is metered and enters the individual train gas treating section. The first part of the gas treating section deals with the acid gas in the feed. CO_2 and H_2S need to be removed to meet product specification and to prevent freezing in the liquefaction section. Gas from Central Luconia can have up to 6.8 mole % of CO_2 and 400 ppm of H_2S. Amine-based solvent is used in the acid gas removal process. Solvent with absorbed acid gases are regenerated in regenerator column at high temperature and low pressure. The acid gases are then incinerated before being discharge safely to the environment. In MLNG, acid gases are incinerated in steam boilers while in MLNG Dua and MLNG Tiga, acid gas thermal incinerators are utilised. The final process of gas treating is the removal of water and mercury up to 1 ppm and $10 ng/sm^3$ respectively.

The natural gas is then ready to be liquefied by using Air Products and Chemicals Inc. (APCI) license process. APCI process uses 2 types of refrigerants, which are propane and mixed component refrigerant (mixture of nitrogen, methane, ethane, propane and butane). Natural gas is first pre-cooled by propane before it is finally chilled to –151 deg C in the Main Cryogenic Heat Exchanger (MCHE) by the mixed component refrigerant. The final cooling down to –161 deg C is by Joule-Thompson expansion through control valve. Finally, LNG is piped to the tank farm for storage at atmospheric pressure. Once the LNG ship is ready, LNG is loaded to the ship from the tank through loading arms at the jetty head. That completes the process, and the LNG is now ready to be used as fuel for power generation upon gasification at the customer's LNG receiving terminal.

2 CHALLENGES FACED BY THE DESIGNER OF MLNG TIGA ACID GAS INCINERATORS

2.1 DESIGN OF LARGE SCALE ACID GAS INCINERATOR IN THE INDUSTRY

The largest acid gas incinerator in the industry has design capacity of 3125 t/d. However, the operation appeared to be unstable due to a number of possible factors. Some of the main factors are acid gas caloric value variations substantially above design, absence of feed forward controls on acid gas flow and caloric value, improper distribution of the fuel gas over the main and auxiliary burners and absence of continues water condensate drainage from the incinerator acid gas windbox.

These acid gas incinerators are vertically fired and designed with main burner and auxiliary burners. The incinerators appeared in practice to be undersized when correct burner mixing of acid gas with air and correct fuel gas distribution to establish flames on the auxiliary burners was not adhered to. Incorrect distribution of air and fuel gas resulted in unstable auxiliary flame conditions and consequently insufficient mixing and residence time to combust all hydrocarbons within the incinerator and light bluish stack flames could become visible from the exhaust stack at night. The auxiliary flame instability introduced variations in flue gas temperature and excess oxygen content that affected the control system stability. The flue gas temperature and excess oxygen fluctuations were further enhanced by the intermittent ingress of condensate water slug from the acid gas distribution windbox into the combustion chamber and the acid gas caloric heating value variations. It appeared in practice that it was impossible for the incinerator control system and hardware, as for instance the incinerator combustion air blowers and dampers, to cope with rapid and large changes in flue gas temperature and oxygen content. As a result, these acid gas incinerators are subjected to frequent trip on either too low or too high flue gas temperature or too low oxygen.

2.2 INCORPORATED PHYSICAL DESIGN IMPROVEMENT IN MLNG TIGA ACID GAS INCINERATOR

MLNG Tiga acid gas incinerator design took a radical approach in order to be able to incinerate large scale amount of acid gas. The old vertically fired main and auxiliary burners design was replaced with horizontal firing burners, tangentially arranged at the incinerator wall. In anticipation of the much higher incinerator load of 3800 t/d of acid gas, the new design is believed to be able so solve the problem of insufficient mixing and residence time in the combustion chamber.

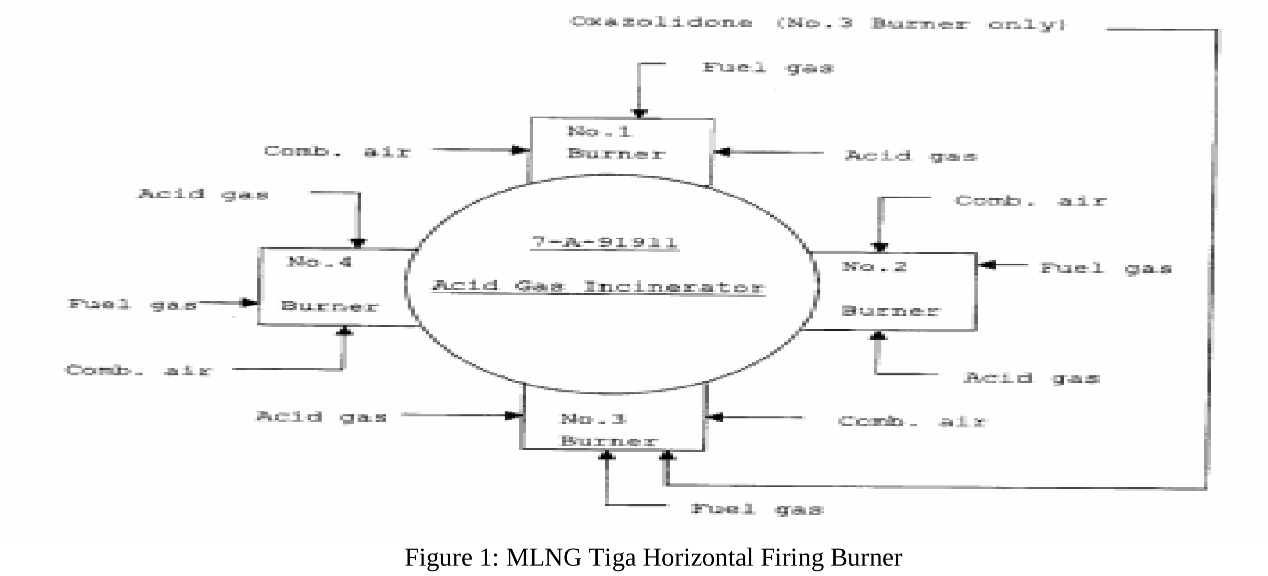

Figure 1: MLNG Tiga Horizontal Firing Burner

The design capacity of the acid gas incinerator was however later reviewed and it was decided that 2 acid gas incinerators per train instead of a single installation would improve the availability of the acid gas incinerator. The design capacity philosophy was also changed to only 100% x 1.1 instead of 150% x 1.1 in the original design. The revised design capacity is justified as that even if one incineration train unit trips, the LNG train production is still possible with turndown throughput to 60%. Although the incineration unit is designed at 55%, it will be able to treat the acid gas correspond to 60% of the feed gas into the LNG train since the unit is designed at highest CO_2 and H_2S concentration and assuming all the aromatic components are absorbed in acid gas removal solvent. In the end, the final design capacity of the acid gas incinerator is 1300 t/d. Even with a lower capacity, the vendor decided to go ahead with the initial design proposal of horizontal tangentially fired burners but with only 4 numbers of burners instead of 6.

The risk with tangentially fired burners is that there is a possibility for the flame detector to detect adjacent flame. Furthermore, the flame will be closer to the combustion chamber wall, hence higher stress to the refractory. This could shorten the life of the refractory as it might see higher temperature than the design adiabatic flame temperature. For vertically fired acid gas incinerator, all of the combustion was taking place in a narrow cylinder of approximately the same diameter as the exhaust stack. The available residence time in the combustion chamber is not being utilized since most of the volume was dead space. MLNG Tiga burners are oriented to give better utilization of the volume, hence increasing residence time and allowing more complete combustion. Furthermore, the proportional volume of combustion chamber to gases was increased to further increase the residence time.

Auxiliary burners for the acid gas are replaced with scroll type burners wrapped around the fuel gas lance burners. Scroll type burner is generally applied to burn low calorific fuel gas in incinerator and boiler. In this case, acid gas is supplied through the scroll gas burner and fuel gas is supplied through multi lance burner.

Combustion air is fed through primary and secondary swirl vane of air register. So as combustion air has swirl momentum, mixing with both straight flow acid gas and fuel gas is made effectively. Primary air register provides 100% air for combustion of fuel gas at the lance burner, 50% air fir combustion of acid gas at the scroll burner and excess air for cooling. Secondary air register on the other hand provides 100% air for combustion of acid gas and excess air for cooling. High adiabatic temperature of the fuel gas flame causes the lower adiabatic temperature of the acid gas flame to mix well with it. Acid gas flame that is heavier is directed towards the center of the fuel gas flame. Secondary air register can be used for mixing of the acid gas and fuel gas by changing the flame temperature and recirculating the flame.

Furthermore, these burners are installed horizontally and tangentially, and so, combustion fuel gas from burners is effectively mixed. Thermal oxidation will also take place efficiently due to the long combustion flue gas trace of horizontal tangential burner installation compared to vertically upper firing incinerator.

The MLNG Tiga acid gas incinerators are designed for a maximum operating temperature of 1100 degrees Celsius to limit the size of the incinerators. Higher operation temperature considerably improved the operational stability. An operating temperature of 800 degC is sufficient for the combustion of H_2S but is insufficient for complete oxidation of aromatics in the acid gas. Benzene and toluene typically require 850 to 950 deg C for complete combustion provide sufficient residence time. The higher operating temperature also increases the reaction rate, thereby reducing the required residence time.

2.3 INCORPORATED CONTROL DESIGN IMPROVEMENT IN MLNG TIGA ACID GAS INCINERATOR

When there is an upset in the LNG train, operator attention will be devoted to the process train. The acid gas incinerator largely has to look after itself through the control system. Hence, in order to ensure stable continuous operation of the acid gas incinerator during steady operation and during upset and disturbances in the natural gas feed composition and the acid gas removal unit, the control system need to be able to function well. With 2 acid gas incinerators per train, there is the possibility of one acid gas incinerator tripping during normal operation. The acid gas flow will be automatically diverted to the remaining acid gas incinerator and the control system needs to react to this fast disturbance. Furthermore, during turndown, there will normally be a lag between cutting back of feed gas rate and acid gas removal solvent circulation rate. There will be an increase in acid gas heating value during the lag and the required response time for the incinerator controls need to cater for the consequent step changes.

MLNG Tiga acid gas incinerator control scheme adopted a double ratio cross limiting control system for fired heater. The incinerator stack temperature acts on the fuel and combustion airflow controller setpoint in parallel, with limits (maximum for fuel, minimum for air) to avoid sub-stoichiometric combustion. In comparison to older incinerator control scheme, where in parallel to adjusting the fuel flow, the total fuel demand signal passes via the air/fuel ratio controller to adjust the setpoint of the combustion airflow controller. Hence, there will be minimum disturbances to the air/fuel ratio on load increase and decrease. The required air/fuel ratio can either be manually set by panel operator, or automatically set by the closed-loop stack oxygen controller. Acid gas flow is included as feedforward signal in MLNG Tiga acid gas incinerator control scheme.

In addition to the limit imposed on the range of the air/fuel ratio controller, limits are also sets on the adjustment of the setpoint of fuel and combustion air as follows. The total fuel flow is multiplied by a factor and provides a minimum limit via a high selector to the total fuel demand signal being sent to the combustion airflow controller setpoint. If the total fuel demand decreases and the actual fuel flows do not react, this signal will limit the decrease in the combustion airflow to prevent sub-stoichiometric combustion. The control system changes from a parallel control system to a “fuel-leading” system (fuel decrease leads air decrease) after the high selector had limited the decrease in combustion airflow.

A similar system applies to the fuel flows. The measured combustion air flow passes through a minimum air/fuel ratio block with setting lower than the air/fuel ratio, and the signal provides a maximum limit via a low selector to the total fuel demand signal to be sent to the fuel flow controller setpoint. If the total fuel demand increases and actual combustion airflow does not follow, this signal will limit the increase in fuel flow demand. The control system changes from a parallel control system to an air leading system (air increase leads fuel increase) after the low selector have limited the increase in fuel flow.

If not all burners are in operation, air that is supplied to the burners not in operation will not be taken into account in the air/fuel ratio control. For this reason, the measured fuel flow signal used for the air/fuel ratio control is multiplied by the ratio of the number of burners installed to the number of burners in operation. Furthermore, if not all burners are in operation, the oxygen measurement will not give proper information on the actual air/fuel ratio at the burner. Therefore the oxygen controller shall be switched automatically to tracking if not all burners are in operation.

Stack temperature override control will increases the amount of combustion air via a high selector to meets its temperature setpoint. It is particularly useful during large variation of acid gas heating value, where the amount of air requested by the air/fuel ratio controller will cause too high temperature in the stack.

Density compensation is added for compensation of the fuel gas flow measurement. As density increases, the mass flow will be higher than the uncompensated value, but at the same time, the LHV decreases. Using both compensations gives about 80% of the correction based on mass flow alone. So the major compensation is for the mass flow correction of the flow meter. For a head type flow meter, density changes of +/- 20% will results in uncorrected flow to be incorrect by +/- 10%. This is an accepted range of error for air/fuel ratio control. However, other variations in acid gas composition and CO_2 content of the fuel gas may give variations in air/fuel ratio of +/- 15%. So the total variations without fuel gas density compensation could be up to +/- 25% and this would be too excessive.

3 ACID GAS INCINERATOR CONTROL VS. FURNACE CONTROL

MLNG Tiga acid gas incinerator control scheme is a vast improvement from the older acid gas incinerator control scheme. However, it is still based on standard fired heater control scheme. The scheme is premised on varying the combustion heat input to meet an external process demand; i.e. process outlet temperature or steam production rate. In this scheme the acid gas is treated as a waste gas flow, supplying heat input to the system.

An incinerator is not a heater. It is an adiabatic reactor, with the incineration (acid) gas, combustion air and supplemental fuel gas as reactants. The operational objective of maintaining target combustion gas (stack) temperature and excess 0_2 concentrations are not obtained by manipulating the total heating value of the fuel supplied, but rather by manipulating the net composition of the reactants (i.e. combustion stoichiometric). Supplemental fuel gas (with a higher heating value) is necessary to produce the required combustion gas temperature. For the incinerator, acid gas is a contributor of combustion heat but it is more significant load on the system (mass of gas/air to be heated to combustion temperature). For an increase in acid gas flow, a proportional increase in fuel gas and combustion air will be required, and vice-versa for a decrease in acid gas flow.

MLNG Tiga acid gas incinerator control scheme attempts to maintain the total combustion heat input at the value called for by the stack temperature controller. For an increase in acid gas flow, this scheme will decrease the fuel gas flow, a move in the opposite direction from the required steady state value. In order to correct this situation, the control scheme will wait for the incinerator stack temperature to deviate from setpoint, only then it would proceed adjusting the fuel gas flow until the correct steady state value is reached.

The acid gas incinerator is expected to display relatively fast response to manipulations, on the order of 5 minutes time constant. Relative to this process dynamic, changes in acid gas or fuel gas compositions are expected to be slow. It is reasonable expectation that the feedback controllers for incinerator temperature and excess O_2 will adequately respond to composition (heating value) changes. However, the disturbance of acid gas flow changes can occur suddenly and may be large. These disturbances may be due to an upstream disturbance or the parallel incinerator tripping, among others. The control scheme should take this fast disturbance into account.

4 STARTUP OF TRAIN 7 ACID GAS INCINERATORS

Train 7 acid gas incinerators were started up in March 2003. Various implementation problems were found during dynamic simulation, mainly related to input and output ranges of calculation relays, and tracking and initialization to achieve bumpless transfer. Control system was further checked onsite by applying “dummy” input values prior to commissioning itself, and various modifications were made to the detailed configurations. As a result, there were no further configuration problems during commissioning.

During firing of the burners it can be seen clearly through the view ports that the combustion was complete without any soot formation and the flame was very stable. Without acid gas, the flame was bright yellowish and due to the tangentially positioned burners, it was circling the combustion chamber.

The scroll burners were found to exhibit flame instabilities at low burner pressure. Consequently, higher active minimum fuel gas pressure setting was implemented. A fuel gas minimum allowable pressure was required to avoid flameout during ignition of a second burner. Mechanical minimum stop for the fuel gas valve was set to be ensure sufficient fuel for combustion of fuel gas at all 4 burners. The minimum stop is needed to ensure continuous firing on all burners when the acid gas incinerator trips to minimum firing when the acid gas is vented and the fuel flow controller is switched to manual with 0% output. The setting has to be low enough that it will not cause too high fuel pressure and consequently high startup load during startup of the first burner.

With the introduction of acid gas, the flame turns blue and becomes much shorter. The change in the color of the flame indicates the increase in UV radiated from the flame and the reduction of infrared radiation. The flame is still very stable and not seems the stability seems not to be affected by further increase in the amount of acid gas.

As the load increases, flame detectors were continually programmed to capture all possible combination of different flame signatures from zero acid gas to maximum acid gas flow. At each burner, primary and secondary air registers were provided to change the ratio of air flowing to the acid gas scroll burner and the fuel gas lance burner. These registers are useful in balancing the air split and help to obtain the best color of flame, indicating sufficiently good mixing and combustion. The split of air also affects the flame detection. If there is too much air going through the secondary air register towards the acid gas scroll burner, then the acid gas flow will be cooled off and the aromatics in the stream will not be combusted. The uncombusted aromatics at the burners will absorb most the UV from the flame and the flame detector will have difficulty in detecting the flame.

5 STEADY OPERATIONS OF TRAIN 7 ACID GAS INCINERATOR

Train 7 acid gas incinerator has been in operation for more than 2 years now. It is taking on average of about 1100 t/d of acid gas daily had never been any problem of insufficient residence time or mixing. The flame continues to be stable at all operating cases and varying acid gas load.

The only problem with the unit is the instability of the flame detector at high acid gas load of 1200 t/d. After rigorous checking and testing done on the flame detector, it is believe that the root cause of the problem is the viewing angle of the flame detector. The position of flame detector is fixed; hence the line of sight of the flame detector cannot be adjusted. As acid gas load on the burner increases, the flame shortens. It is likely that the flame shortens to the extent that the line of sight of the flame detector does not cross the flame anymore. This is supported by the fact that the flame can be seen to be visually stable at 1200 t/d of acid gas, radiating a lot of UV radiation as the indicated by the bluish color of the flame. Hence, the maximum flow of acid gas to the acid gas incinerator is limited to 1200 t/d only, which is about 92% of design capacity.

At steady state, the control system is able to maintain all control variables at setpoint without any instability. Constant stack temperature and oxygen content suggests good mixing and combustion. Heating value of acid gas continues to be high, therefore the override temperature control continuously selected to control the combustion air. However, as expected, on sudden large changes of acid gas load to the acid gas incinerator, the disturbance on the stack temperature is large. Due to the fact that the control scheme is based on standard fired heater instead of adiabatic reactor, increase of acid gas flow will decrease the fuel gas flow, which is a move on the opposite direction. Fuel gas flow will only be increased from the action of the stack temperature controller once the measured temperature starts to deviate from the setpoint. Nevertheless, in most operational upsets, the swing in the stack temperature is recovered relatively fast and is still within operational margin; hence the acid gas incinerator is still able to stay online on changes of acid gas load.

In June 2003, fire broke out inside the gas turbines and incinerators combined stack for about 3 minutes. The root cause of the fire was the presence of unburned hydrocarbon from the acid gas stream in combustible environment in the combined stack. Rich amount of hydrocarbon in the acid gas was due to the high amount of hydrocarbon being released from acid gas removal solvent when heat was restored to the acid gas removal regenerator column after an earlier trip of the heat transfer fluid pumps on loss of power to Train 7. Following that, modifications were made to the safeguarding system to trip the incinerator to minimum firing on trip of incinerator air blower and on MCHE trip. Also, it was included in the Operational Procedures Guide that the acid gas removal unit should be started up with acid gas routed to vent, and only diverted to incinerator after stable operation has been established. This is to ensure that during startup and operational upsets in the acid gas removal unit, acid gas will not be routed to the acid gas incinerator as the heating value of the acid gas can be considerably higher than what the acid gas incinerator is designed for.

6 FUTURE EXPECTATIONS AND CONCLUDING REMARKS

In conclusion, the design of the tangentially fired MLNG Tiga acid gas incinerator was a story of success so far. Benefited from vast lessons learnt of existing large scale acid gas incinerator operations, large improvements were made in both the physical design and control scheme of the incinerator. Startup and steady operations were not troubled by major difficulties and constraints. Although the maximum capacity of the incinerator is currently limited to only 92%, this is not attributed to the stability of the flame or operating conditions that is beyond the design envelope. It was simply due to the limited line of sight of the flame detector. Even though more are understood of the process now, there are yet many unknowns to be mastered. Design of large-scale acid gas incinerators is still challenging especially from process control point of view.

6.1 PHYSICAL DESIGN OF ACID GAS INCINERATOR

Startup and operational experience of acid gas incinerator in MLNG Tiga had so far proven that the theory behind horizontal firing burners with tangential arrangement at the incinerator wall. Mixing started at the point the reactants (acid gas, fuel gas and combustion air) are introduced into the acid gas incinerator. The combination of the acid gas scroll burner and the fuel gas lance burner with combustion air that comes through primary and secondary registers ensures that the reactants are sufficiently mix as it is combusted at the burners. The well-mixed hot combustion gases from each burner are then thermally oxidized as it mixes with each other along the spiral path from the combustion chamber to the top of the stack.

The horizontal firing and tangentially arranged burner had proved itself to be a superior design that solves the problem of improper mixing ant insufficient residence time. Maximum utilization of the incinerator volume means that capital cost can be saved in size reduction of the acid gas incinerator. It is a clear way forward in future acid gas incinerator physical design.

6.2 CONTROL SCHEME OF ACID GAS INCINERATOR

The standard fired heater control scheme that was implemented worked well in steady state but less so in transient conditions. Though the disturbances is normally not large enough to cause a trip during large load changes, the resulting transient is not desirable and can cause problem for a larger design capacity of acid gas incinerator. Hence to obtain the control objective of maintaining the stack temperature and O_2 concentration, the net composition of the reactants need to be varied rather than varying the total heating value of the fuel supplied. For an increase in acid gas flow, the amount of fuel gas supplied and combustion air need to be increased and vise versa.