

Biogas Engines - Optimising the Performance of Complex Processes

Overview

In this case study the optimisation of unstable running of biogas engines is examined.

Biogas is produced as a byproduct of waste water treatment plants. The amount and quality of the gas depend on the quantity and composition of the effluent being treated by the plant. The gas can be utilized to produce electricity, using positive displacement engines (same type as a car engine). Burning the gas in an engine also produce heat which can be utilized elsewhere in the plant (I.E. to heat up the digester to optimum temperature). Where biogas is not sufficient natural gas is used to augment biogas as fuel for the engines. Where excess biogas is produced it is flared. Due to the complexity of the process and the disturbances caused by variable biogas production (See Figure 1) the controls for the engines can become unstable, causing unnecessary engine trips and biogas flaring with a simultaneous high natural gas usage (see Figure 2).

More often than not the process would be run in Manual which causes excessive gas flaring or tripping of the engines due to gas starvation.

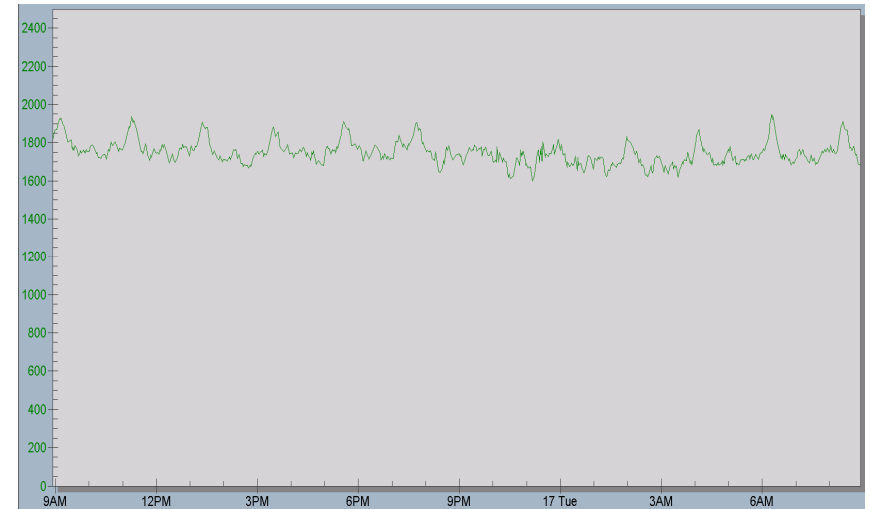


Figure 1 - Biogas Production

The business objectives of the engine optimization was a reduction in natural gas usage and biogas flaring and a reduction in instances of engine tripping. The end result would be a positive cost benefit with less effort required by operational personnel to run equipment.

Optimizing the control system for the biogas engines had two goals:

1. Process stability - To get the engines running in Auto and reduce the trips and start ups, and
2. Process optimization - Once the process was stable minimize biogas flaring and natural gas usage.

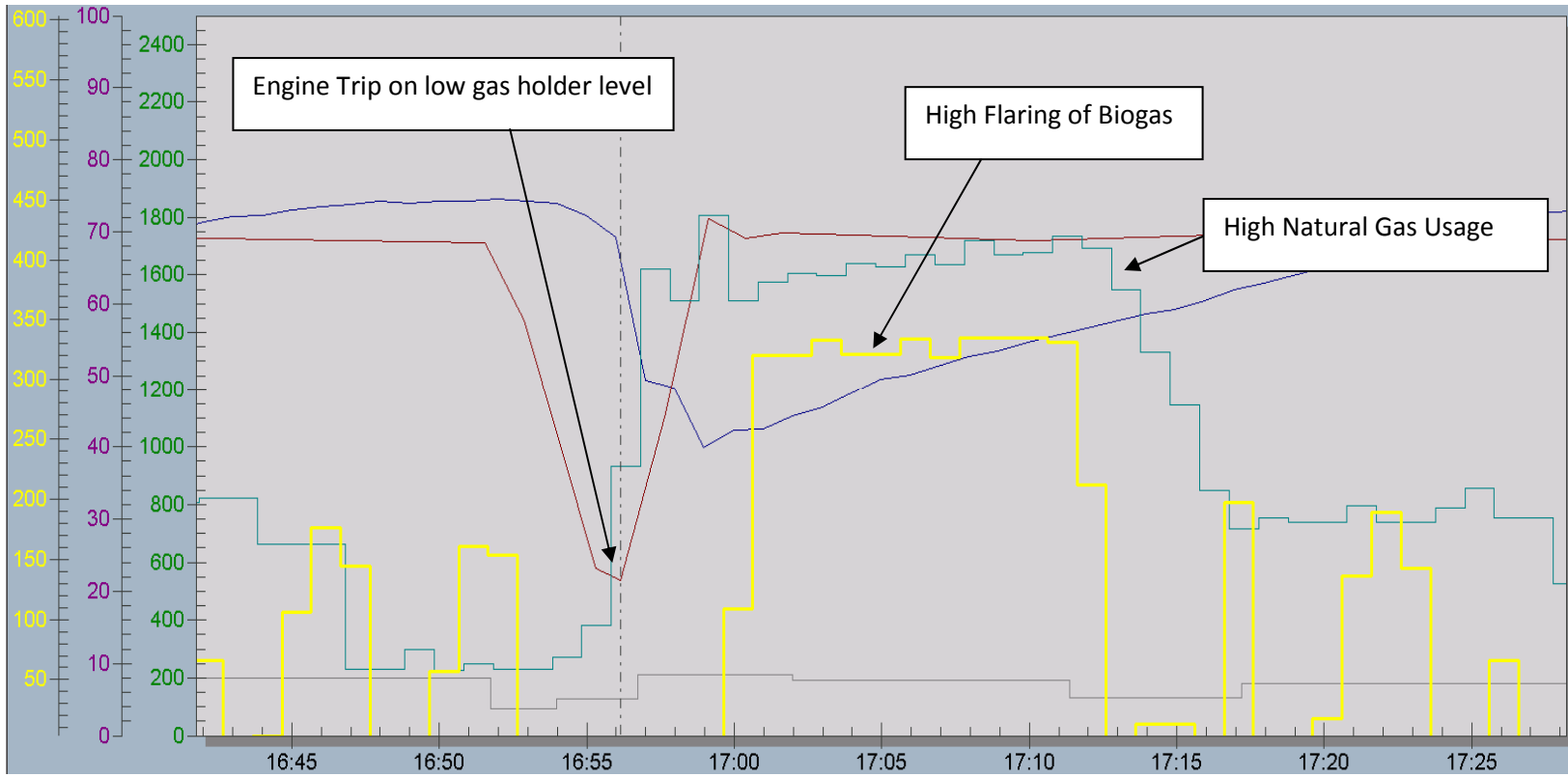


Figure 2 - Engines Tripping

Layout

The total process consists of (please refer to Figure 3 for a schematic of the system):

1. Seven digesters producing biogas. Each digester has a biogas flowmeter. Please see Figure 2 for a trend of the variable production of biogas
2. Gas is fed into a low pressure gas holder. The gas holder is intended to be a buffer in the system
3. Four flares that will flare of gas once the low pressure gas holder reaches its upper limit
4. Four gas blowers which purpose is to raise the pressure of the biogas from 2.5kPa to 45kPa required for optimum engine performance.
5. Pipe lines transferring the gas across the plant to where it is being consumed by the engines
6. Two engines which can either run on 100% natural gas or 100% biogas. Each engine is equipped with t flowmeter for biogas and natural gas consumption flow measurement.
7. Two engines that can blend natural gas and biogas. These engines are primary ones for controls. Each engine is equipped with t flowmeter for biogas and natural gas consumption flow measurement.

Process Constraints

Blowers

Each blower has several protection interlocks that cause them to trip and lock out. These interlocks are:

1. Low suction pressure
2. Low pressure gas holder level below 20%
3. High discharge pressure
4. High Discharge temperature

The blowers need to be operated within these parameters to keep the system stable.

Engines

On a blower trip the PID output to the blending engines reset to the minimum output. This reduces the biogas consumed, causing the rest of the biogas to be flared while at the same time using natural gas to run the engines. A costly and inefficient occurrence .

The engines will also trip out on low and high biogas supply pressure.

Control System Problems

Problems with the previous control regime:

1. A major symptom was a rapid and uncontrollable fluctuation in the low pressure gas holder. This is caused by the blowers ramping up / down, engines starting and stopping and the variability in biogas production
2. Staging of the blower controls. At startup the control of the blower pressure would ramp up to 80% and a second blower would start at the same output percentage as the first. Obviously almost twice the amount of gas would be transferred from the low pressure to the high pressure gas side. The consequence would be a sudden and drastic drop in the low pressure gas holder level
3. Engine biogas blending control was based on trying to maintain a set level in the low pressure gas holder. This strategy completely ignored the variation in biogas production and biogas supply pressure.
4. The sheer number of permutations and combinations of equipment in operation. Each permutation and combination has a different open loop transfer function. A control strategy had to be designed to overcome this.
5. Equipment often left in Manual operation which caused unnecessary flaring of biogas. See Figure 4 for an example trend of almost continuous flaring of biogas.

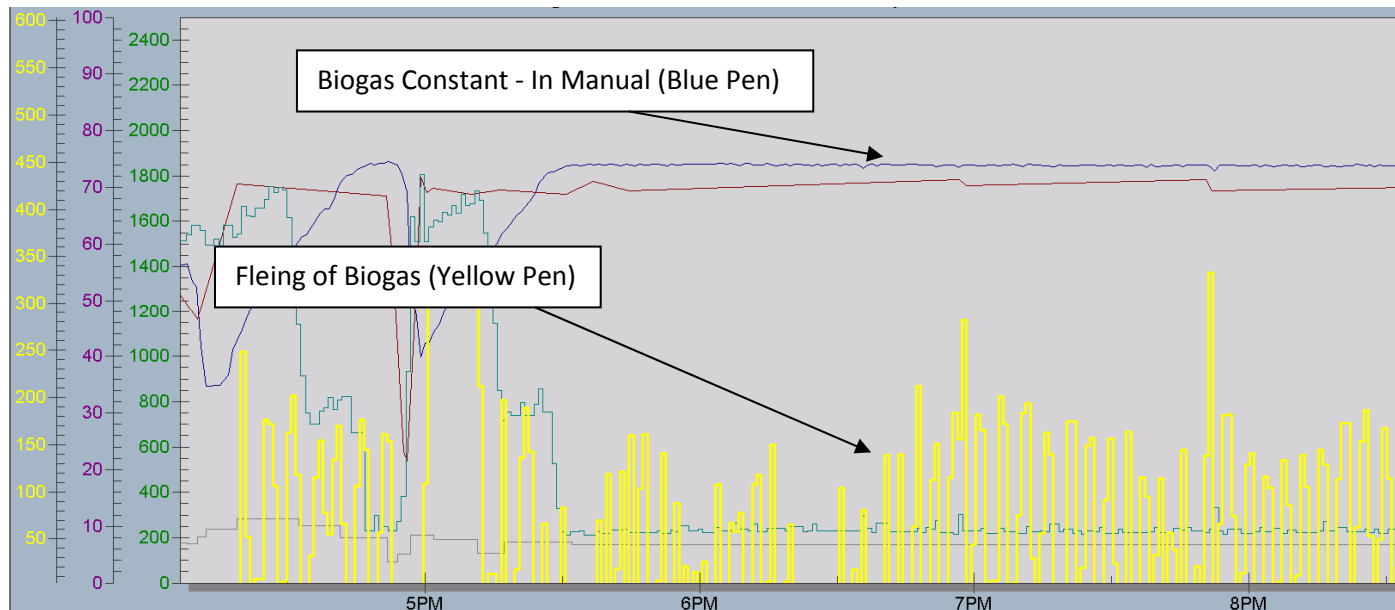


Figure 4 - Biogas Flaring

Solution

Engines

The overall strategy for controlling the blending engines were changed. Control wa based on the following principle:

$$\text{Biogas Consumed} = \text{Biogas Produced} \pm (\text{LP Gas Holder Level})/dt$$

Please see Figure 3 for a trend of the Implemented gas follow control.

The control will balance the biogas inflows to the outflows. Due to errors in all the flow meters (11 in total) there will always be an imbalance between the real biogas inflow and outflow when the two totals are reading equal. The physical discrepancy between the two will cause the gas holder level to either increase or decrease. Please see Figure 5 for a trend of the gas following controls.

The addition a level controller will offset the difference an measurement between inflow and outflow. The level controller output will be added to the measured flow rate to produce a set point for the biogas PID loop. The output of the level controller should be scaled to produce a trim effect. (+20% to -20% of the total flow scale).

Because the open loop transfer function changes depending on which combination of engines are running five different gains and integral time constants were programmed into the system. the system would detect which combination is running and then pass the relevant PID tuning parameters to the controller. This was done for both the biogas and low pressure gas holder level controllers. Tuning proves to be challenging because the system was inherently unstable and the two variables (flow and level) could not be isolated from each other to determine process gain and time constants. The combinations that were catered for are:

1. One blending engine running
2. One blending and one fixed engine running
3. Two fixed and one blending engine running

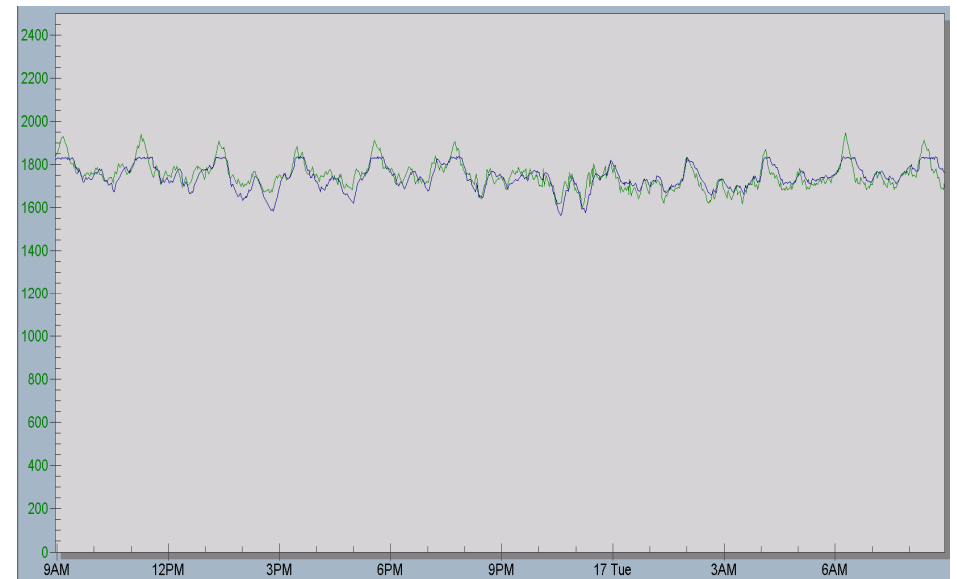


Figure 5 - Gas Following

4. One fixed and two blending engines running and
5. All four engines running

Blowers

Getting the blower to respond to the processes better was a major concern. A deadtime exists due to the long pipelines between the blowers and the engines. Please see Figure 5 for a setup of the blower controls. It was therefore necessary to implement a cascade controller. The master PID controller controlling the eventual engine manifold pressure (45kPA). Its output was a setpoint to the slave controller which controlled the immediate blower controls which looked at the pressure at the blower discharge.

The blower pressure controls were further complicated by the fact that the open loop transfer function changes when one two or three blowers are running. A similar strategy as for the biogas PID controller was adopted where three different gain and integral time constants were passed to the slave pressure controller depending on how many blowers were in operation.

Interlocks on the blowers were set to trip out the blowers instantaneously. Spurious or transitional data spikes would cause the blowers to trip out, which in turn would cause the biogas controller to go to its minimum output, which in turn causes a massive disruption in both blower pressure and low pressure gas holder level. A de-bounce time of 30seconds were added to each interlock to ensure the interlock condition was not transitional. The effect was a 66% reduction in tripping instances.

The outcome

Engines are now left in automatic control. Trips of blowers or engines rarely occur. Engines are mainly stopped because of natural gas supply contract constraints and for maintenance reasons. Please see Figure 6 for a trend of typical running after the controls were implemented.

Please see Figure 6 for a comparison of the engine controls before and after optimization. Please note that there is little flaring present in the "After" trend. If compared to Figure 4 it can be seen that flaring is reduced considerably. Figure 4 represents five hours and Figure 6 the whole day.

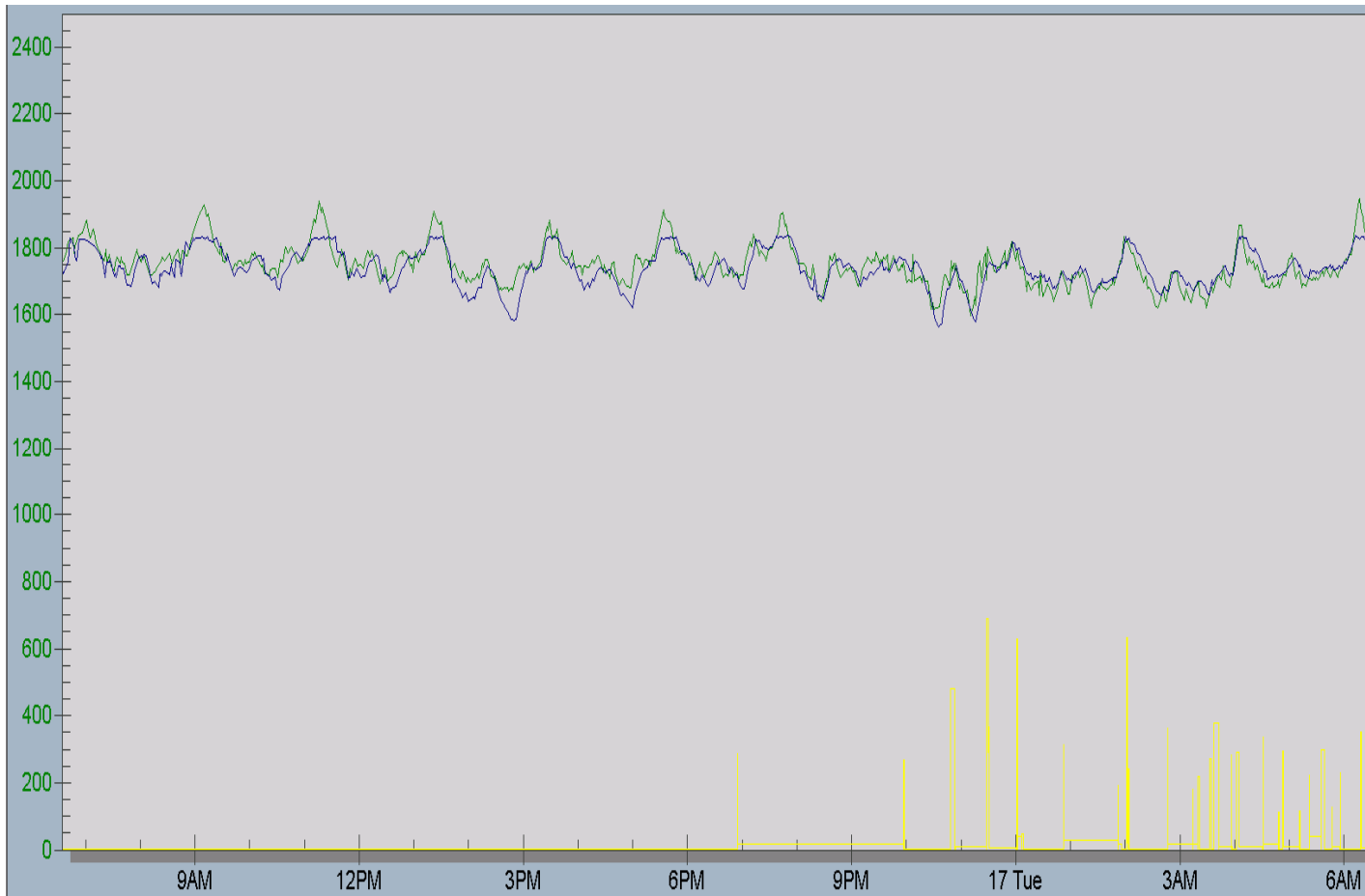


Figure 6