FLARE TRICKS

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ABSTRACT
Landfill gas flare systems often seem like a large "black box" just waiting for something to go wrong, with few people willing to understand the fundamentals of flare design and operation. With a little basic knowledge and some "tricks of the trade", you can learn simple, easy ways to minimize O&M time, stay in compliance, and minimize complaints about the flare. There are three common operational questions engineers and operators continue to ask. How can I get a greater turndown with my flare? How can I eliminate the rumbling or vibrations from my flare? And, how can I effectively control landfill gas to a third party user?

People from all aspects of the landfill industry have questions on how to minimize their time and efforts with respect to some function in their landfill gas flare system. Low flow rates, low methane concentrations, high oxygen concentrations, and third party users can wreak havoc with the operation of your flare system. Understanding how these key elements affect the combustion process through landfill gas burner flow distribution and the flow of combustion air are critical to ease of operation and maintenance of the system. Leaning how to utilize these parameters to your advantage can save you time and money. This paper will share the basic design concepts of landfill flares as well as letting out of the bag common "tricks" that can be used for properly controlling these concerns.

Before these "tricks" are discussed, it is important to understand the fundamental processes of combustion inside the flare. With this knowledge, it is possible to make logical, step by step changes to meet the requirements of the given situation. This will result in minimizing O&M time, staying in compliance, keeping neighbors happy, and reducing an end user's down time can be realized, just by learning a few "Flare Tricks".

COMBUSTION 101
Most people understand how to respond to an operational issue on a landfill gas flare system when it involves an electrical or mechanical failure. However, when the "black box" we call a flare is not operating or responding as it should under normal operating conditions, these same people seem to struggle for a solution. In order to formulate an appropriate response to a given abnormal flare operating condition, it is very important to first understand some basic combustion principles.

Combustion of landfill gas is primarily limited to the oxidation of methane (CH_4) or in other words, the combination of methane, oxygen, and heat. The oxygen obtained for this process is introduced in the flare with atmospheric air. While several hundred parts per million of Non Methane Organic Compounds (NMOC) are generally present in landfill gas, these amounts are insignificant in comparison to the amount of methane in the gas and are ignored for combustion calculations. Carbon dioxide (CO_2), the other major compound in landfill gas is an inert, which passes through the flare system unaffected and is also removed from this basic combustion discussion. Therefore, when we talk about the oxidation of methane, we can describe it by the following reaction:

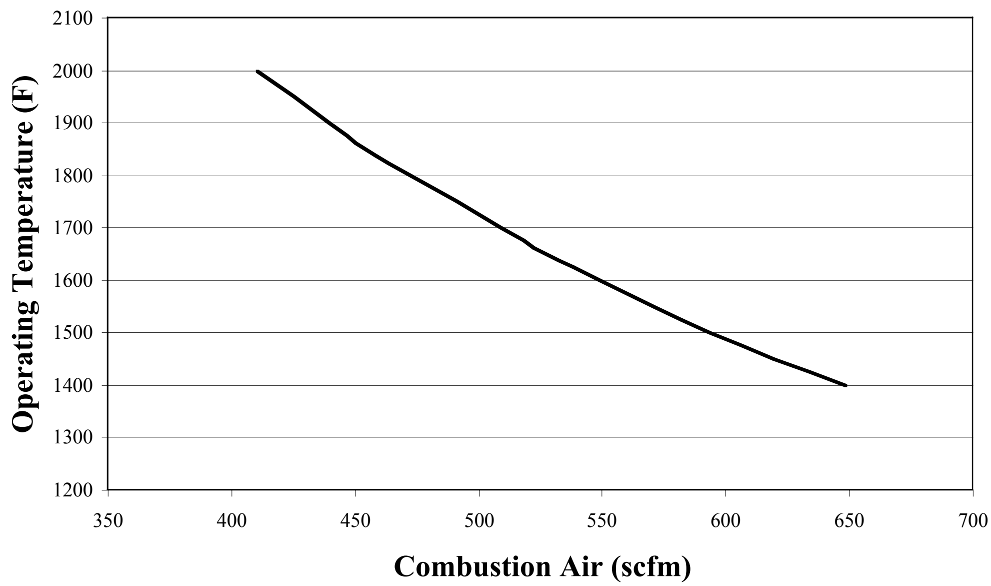
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The products of the above stoichiometric reaction are merely carbon dioxide and water. This reaction is very simple when looking at only the reactants on the left of the arrow and the products on the right. In reality, each molecule of methane and oxygen is broken down into individual atoms before they recombine into the product molecules. Very simplistically, the above reaction can be rewritten as follows:

$$CH_4 + 2O_2 \rightarrow C{+}H{+}H{+}H{+}H{+}O{+}O{+}O{+}O \rightarrow CO_2 + 2H_2O$$

In order to make this reaction happen, heat is required to start the process. Once the methane molecule has been brought up to its autoignition temperature (Table 1), enough heat is generated from the molecular bonds breaking to continue the process as long as methane and oxygen are present. After each molecule has been broken down into its individual atoms, those atoms then recombine into different molecules, in this case carbon dioxide and water.

Combustion Air Required per 1.0 MMBTU of Landfill Gas



Graph 1

Autoignition Temperature

Component	Temperature (°F)
Methane	999
Propane	871
Butane	806
Pentane	588
Hexane	477

Table 1

Flammability Limits

Component	LEL	UEL
	(volume % in air)	
Methane	5.0	15.0
Propane	2.1	9.5
Butane	1.8	8.4
Pentane	1.4	8.3
Hexane	1.2	7.7

Table 2

The amount of oxygen required to oxidize methane has been determined and is defined as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL), or otherwise known as Flammability Limits. Since the oxygen required for this process is derived from atmospheric air, the UEL and LEL are stated as a function of the compound to be oxidized and air. Table 2 is an example of the flammability limits of various compounds.

As Table 2 indicates, a volume of air that contains between 5.0% and 15.0% methane is flammable.

Maintaining this mixture of methane and air is critical to the combustion process, because if the mixture goes below the LEL or above the UEL, the combustion process ceases. This is precisely what happens when flares “rumble” or “vibrate”.

Once the proper amount of air and methane mix, the autoignition temperature has been reached, the combustion process is stable, now the temperature must be controlled. This is done by modulating air dampers at the base of an enclosed flare (Fig. 1).

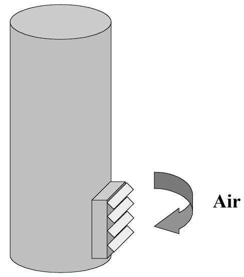


Figure 1

FLARE TURNDOWN

Flare turndown can be expressed in two ways: flow rate turndown and heat release turndown. In each case, we are describing a ratio from maximum to minimum. For example, the flow rate turndown from 2000 scfm to 200 scfm would be 10:1. However, since enclosed flares are designed based on heat duty input in MMBtu/Hr, the most accurate analysis of an enclosed flare is the heat release method.

The amount of turndown capable for a given enclosed flare is primarily based on the amount of combustion air entering the stack. As indicated in the Operating Temperature vs. Combustion Air Graph (Graph 1), the larger the amounts of combustion air correlate to decreasing operating temperatures. Therefore, the key to maintaining the desired operating temperature inside an enclosed flare, at low landfill gas flow rates, is to minimize the amount of combustion air entering the stack. This can be accomplished by the following:

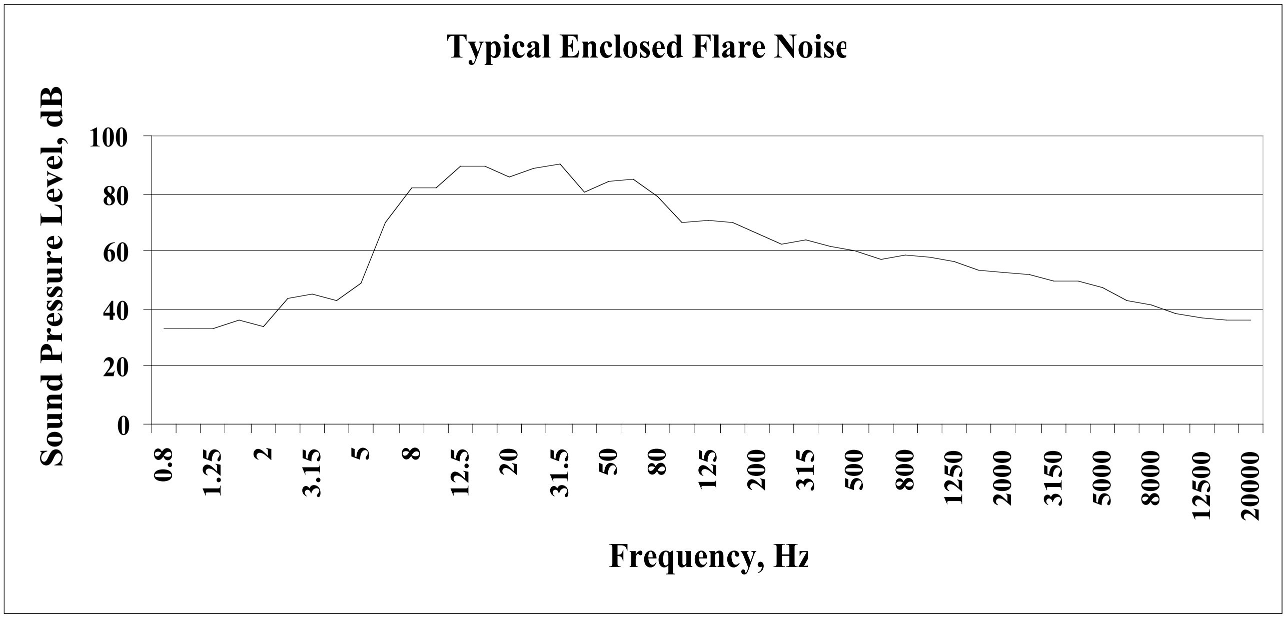
- Fully closing both the manual and automatic air dampers.
- Removing one or more of the air dampers and replacing them with a steel blind plate.
- Replacing an air damper with a partial blind plate and a smaller air damper, generally 15% to 30% in size.
- Any combination of the above.

While decreasing the air flow into the stack will increase the operating temperature of the enclosed flare, the lower flow rates of the landfill gas will also have impacts on other aspects of normal flare operation. These issues are the initial burner ignition at a low flow rate, poor air and gas distribution, and a lower heat profile.

At extremely low landfill gas flow rates, the flow momentum is reduced such that the proper distribution in multiple burner tips is less than desired. Since the gas will flow towards the path of least resistance, it is not distributed correctly between the existing burners. Because of this, it becomes difficult to "cross light" from burner to burner to establish a stable flame during the initial start-up. Small amounts of landfill gas can flow unburned through certain burners, allowing gas to build up in the stack. When the light-off eventually takes place, it happens suddenly with a contained explosion. In order to prevent this low flow distribution issue, some of the burners can be replaced with blind flanges or in some cases the burner holes can be plugged in order to divert the gas flow to the remaining burners. The number of burners to be removed and have blind flanges installed must be limited by the maximum flow rate per burner tip, but must also allow for the maximum required flow from the flare. If it is desired to have the original maximum design flow rate on the enclosed flare, it will not be possible to remove and blind burners.

Just as low landfill gas flow has poor distribution through the burners, the same is true with the required combustion air. The most critical factor in the combustion process is having the appropriate amount of air to landfill gas ratio for each burner. If burner tips are removed for proper gas flow distribution, the corresponding air flow around the removed burners should also be blocked. This can be accomplished by adding an insulated cover in the annular space of the removed or plugged burner tip. The cover shall be installed so that combustion air can no longer enter the enclosed flare around the removed burner. With this cover in place, the air flow is now diverted to the burner(s) that require the combustion air.

Now that the combustion air flow has been minimize and the gas and air flow have been properly diverted inside the flare stack, it is now important to be able to measure the temperature at these extremely low flow rates and/or methane concentrations. On a typical enclosed flare, the lowest thermocouple location in the stack is at an elevation of 17'-0". Under extreme turndown conditions, it is impossible to maintain the normal operating temperature at this thermocouple elevation, therefore, the thermocouple must be moved to a lower elevation in the stack. There are two criteria for this: proper orientation and proper elevation. The most effective orientation for the new lower thermocouple is to place it directly over a burner, preferably a burner symmetrically placed in the middle of the remaining burners. The applicable requirements for retention time will govern over the proper elevation. Most air permits for enclosed flares require a 0.6 second retention time at the permitted operating temperature. For the lower stack thermocouple elevation, at least 0.6 seconds must be achieved at this elevation for the desired turndown. When gas flow rate increases and the retention



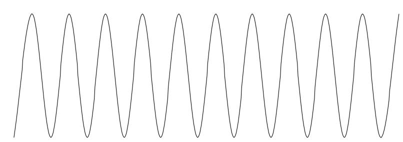
Graph 2

time goes below 0.6 seconds, the next higher thermocouple in the stack must be selected to control the operating temperature.

FLARE RUMBLING AND VIBRATIONS

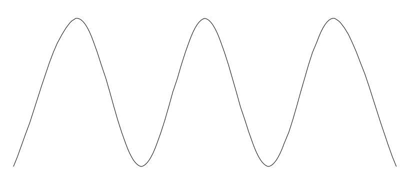
Rumblings and vibrations from enclosed flares can be the most troublesome operational consequence experienced by companies today. They have been known to rattle doors, break windows, knock pictures off the wall, and have been experienced at locations several miles from the source. They have been documented in newspapers from Pennsylvania to California and have cost companies hundreds of thousands of dollars in capital and operational expenses.

Enclosed flare rumblings and vibrations are actually attributed to the "combustion noise" as it takes place inside the flare itself. As the combustion process takes place, noise is generated from the rapid expansion of gases as they go from ambient conditions to the desired operating temperature. This noise is also referred to as Sound Pressure Level (SPL) and measured in decibels (dB). The SPL occurs in frequencies measured in cycles per second, or Hertz, and can range from 1 Hz to 100 kHz. The typical threshold of hearing for humans is generally 20 Hz to 20 kHz. Graph 2 shows the noise generated from an actual enclosed landfill gas flare and indicates higher SPL is generated at the lower frequencies, which is typical for combustion noise. Since the lower frequencies have a longer distance between amplitudes as indicated in Fig. 2



High Frequency

Fig. 2



Low Frequency

Fig. 3

and Fig. 3, they will travel a much longer distance before they are attenuated. An example of this is a car stereo system. At a distance 100 feet away from a car, the primary sound a person would hear is the low frequency bass coming from the sub-woofer, while the sound would be normal to a person inside the car. This is same reason combustion noise can be heard from long distances.

To compound the problem, the rumbling and vibrations observed from an enclosed flare are the direct result of unstable combustion taking place. Unstable combustion is normally detected as very erratic spikes in the SPL in the range of 1 Hz to 50 Hz. Very often, this noise is below the 20Hz threshold of hearing, so only pulsations are felt from the sound pressure. These are the actual pulsations that are a nuisance and can cause damage.

Unstable combustion is a result of landfill gas and air not mixing in the correct proportions to generate a constant, stable flame. As stated in Table 2, in order for landfill gas to burn, it must be within the flammable limits. The pulsations from the unstable combustion occur when the landfill gas is rapidly moving in and out of the flammability limits and then is compounded by the rapid expansion of the gases due to the drastic temperature increase. Specifically, the oxygen molecules are not mixing with the methane molecules in the correct proportions.

In order to correct the rumbling and vibration issues with enclosed flares, the mixing energy of either the landfill gas or air must be changed. The correct change in turbulence will result in a stable burn. In many cases, merely changing the operating temperature in the stack will cease the rumbling and or vibrations being experienced. The operating temperature is changed by opening or closing the combustion air louvers at the base of the stack, which increases or decreases the air flow. This change in air flow has a resultant change in the turbulence or mixing energy between the landfill gas and air. The same can be accomplished by increasing or decreasing the landfill gas flow rate, although this is less desirable. In the most extreme cases, the entire burner assembly must be replaced inside the flare.

GAS TO A THIRD PARTY USER

Whether you have an existing landfill gas flare system or you require a future backup for a gas utilization project, interfacing with a primary user can be difficult. In addition to the critical communication required between the flare control panel and the gas utilization source, it is important to optimize the performance of the overall system.

A gas utilization project is normally designed to accept a pre-set not to exceed amount of landfill gas where the flare system is designed to accept all the gas a landfill can generate. Because of this flow rate difference, one of two things generally happen. Either the flare system is acting as a backup and burning gas that the utilization project does not require, or the flare is not utilized properly and the gas is not being fully extracted from the landfill. In order to design a proper interfacing system, the following three items need to be addressed:

- Supplying gas to the utilization project
- Flare turndown
- Communication between the flare and the utilization project

<u>Supplying gas to the utilization project</u>

A gas project usually requires a positive displacement compressor to pressurize the landfill gas in order to meet the requirements of the internal combustion engine, turbine, pipeline, etc.. While it is possible that this same compressor could pull directly from the landfill, it is more effective to send gas to the compressor from the landfill gas blowers, unless an elaborate control scheme is put into place.

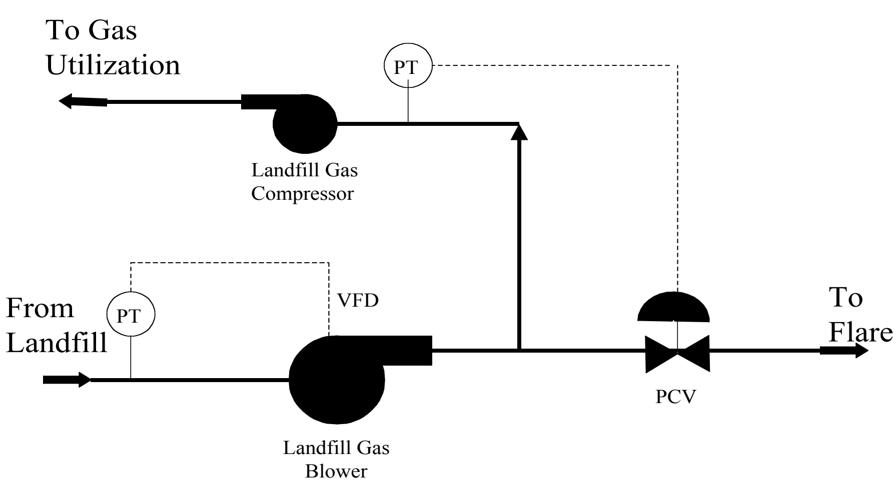


Fig. 4

If the compressor were to extract gas directly from the landfill, the vacuum generated on the collection system must always be less than the capability of the landfill gas flare blowers. This is possible under ideal conditions, but since the compressor is likely to be a positive displacement device, it will get the flow it wants or it will keep increasing the vacuum until it does. If the vacuum increases to the limit of the landfill gas blowers, then it becomes impossible to extract all the available gas from the landfill. Even a slight increase in the vacuum from the compressor can change the dynamics of the collection system.

A more common approach is to let the flare system blowers extract gas from the landfill as shown in Fig. 4. In this case, a vacuum transmitter on the collection system sends a signal to a variable frequency drive (VFD) on the gas blower motor. A PID loop then maintains a constant vacuum on the system to allow all of the gas to be extracted, regardless of the condition. Once all the gas is being collected, it can then be sent either to the gas utilization project, the flare, or both. This is done by adding a pressure transmitter in the gas utilization header and a pressure control valve. The PID loop in this scenario maintains a constant pressure to the compressor to meet its demand. Any excess gas will automatically go to the flare. This simple control system will also require less maintenance and is easier to operate than the alternative.

Flare turndown

In instances where the gas utilization facility uses almost all the landfill gas available, the flare must be capable of turndowns in excess of the original design. The turndown modification in this case is more critical, because the flare must also be capable of operation at the maximum flow rate. With this criteria, the most common solution is to add a thermocouple at approximately 8' to 10' elevation for use only at extremely low flow rates. This additional thermocouple will allow the flare to maintain the operating temperature at a lower flow rate than the original design. If the air permit for the flare does not specify a minimum operating temperature, then the flow rate can easily be decreased further.

In extreme turndown conditions, the minimum flow rate to the flare must be maintained or the operating temperature cannot be controlled. This can easily be achieved with either a mechanical or a software minimum stop placed on the pressure control valve. The minimum stop set point for the control valve must be configured in the field and shall not allow the valve to close past what is required for the minimum flow condition. If the minimum stop is not incorporated into the pressure control valve, then the flare will automatically shut down on low operating temperature or flame failure, unless this shut down is enabled.

Communication

Communication between the flare system and the gas utilization project can be critical to both operations. The main items that need to be incorporated into the flare control panel to maximize the operation of the overall system are as follows:

- Blower operation
- Pressure control
- Status of operation

Blower operation: Landfill gas blowers normally shutdown when the flare shuts down. Under the gas utilization scenario, the blowers must remain in operation even if the flare shuts down. Therefore, logic must be added to the flare control panel such that both the flare and gas compressor must shut down in order to shut down flare blowers.

In addition to changing the blower shut down logic, the logic for the pressure control valve must also be incorporated. For example, in the case of a flare shutdown, the pressure control valve will close fully diverting all the gas to the compressor. Since the compressor cannot take all the gas available, the PID control loop of the blower must now be changed from vacuum control to pressure control based on the discharge header pressure transmitter.

Pressure control: Since the compressor for the gas utilization project is likely a positive displacement machine, it can easily overcome the incoming header pressure if its flow demand increases. If this does happen, it is possible to pull landfill gas out of the flare, and possibly even air into the system before it has a chance to shutdown. In addition, if the compressor demand is greater than the amount of gas available, it will pull through the landfill gas blowers, causing an over-extraction on the landfill.

In order to compensate for the scenario described above, a low pressure alarm and low pressure shut down should be added to the flare control logic. Therefore, if the pressure in the blower discharge header decreases to a certain level below the operating set point, an alarm signal is sent to the gas utilization facility. If the pressure continues to decrease below the pressure set point, the landfill gas blowers will shut down.

Status of operation: The gas utilization project is likely to require trained operating technicians for their facility. Since the flare system will not have this type of operating personnel, it is important that the flare control panel report all the required status back to the gas facility. Also, just as important, the gas facility must provide certain information to the flare control panel.

The flare control panel, as a minimum, must receive a signal from the gas facility that it is ready to begin operation. This will allow the actuation of the pressure control valve. While other status signals can be received from the gas facility, they are not required for a fully functional system. As for the gas facility, it can retrieve any status available from the control panel, including flare status, flow rate, pressure, temperature, vacuum, etc.

CONCLUSION

Minimizing the operational flow rate of a flare, eliminating rumblings and vibrations, and controlling gas to a third party user can be easily accomplished with some basic operation and design knowledge as well as a few secrets from the manufacturer. Minimizing O&M time, staying in compliance, keeping neighbors happy, and reducing an end user's down time can be realized, just by learning a few "Flare Tricks".

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