Benefits of an Enclosed Gob Well Flare Design for Underground Coal Mines

Addendum to:

Conceptual Design for a Coal Mine Gob Well Flare
(EPA 430-R-99-012; August 1999)

June, 2000

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I. INTRODUCTION

This paper considers the benefits offered by an enclosed flare (also known as a thermal oxidizer flare) for use at underground coal mine gob wells. It addresses three important issues for consideration before any selection of flaring technology is made; namely, industry/public acceptance, verifiability of carbon credits, and cost.

II. DESCRIPTION OF THE ENCLOSED FLARE

Enclosed Flare

The enclosed flare consists of a vertical, refractory-lined combustion chamber that effectively eliminates any visible flame. Because the flame is enclosed, there is no thermal radiation from the flare at ground level, thus making it safe to work around. The enclosed design also reduces noise associated with the flare. The burner is located at ground level and is designed to ensure the greatest destruction efficiency under maximum burner turn-down. Combustion air enters the combustion chamber from below the burner through automatically controlled louvers or dampers.

Open Flare

Sample ports located near the top of the chamber facilitate sampling of the exhaust gas as well as recording temperature and gas flow/velocity.

III. INDUSTRY/PUBLIC ACCEPTANCE

Open flares are widely used at landfills, chemical plants, and refineries. However, even though they embody redundant safety features, acceptance of the open flare at a coal mine may be hindered by the perception that open flames pose safety hazards. The enclosed flare addresses this potential concern, and also provides other benefits, as discussed below.

1. At all times the open flare shows a visible flame, which becomes more obvious during the night hours. The enclosed flare, however, dispels what may be a concern of the general public, mine workers, or mine owners: that a visible flame spells danger. While, from an engineer's point of view, redundant safety devices (such as liquid traps, flame arrestors, combustion controls, temperature and pressure sensors, etc.) can be built into the open flare system, overcoming the perception of danger may be difficult. By its inherent design, the enclosed flare avoids this problem because the flame, although present, is fully enclosed and is NOT visible.

2. The visual appearance of the enclosed flare installation is similar to that of a vertical storage tank.

3. The enclosed flare's numerous burner tips contribute another level of redundancy in the flare's safety design.

4. A flare may serve one or more gob wells. The design of an open flare must allow sufficient stack height to ensure safe conditions for personnel working at its base. For example, a typical well producing 1,400 scfm of gob gas (see Section V) would require an open flare 20 feet high. If two or three similar wells were connected to a single flare, the height of the flare would be 25 feet or 32 feet, respectively. The higher the flare, the more visible it becomes from a distance. In addition, maintenance of the flare tip and pilot burner (located at the top of the flare) is more difficult as the height increases.

   The enclosed flare must also be larger as the gas flow is increased. However, because the size of the enclosed design is a function of velocity of the gas through the body of the flare, the enclosed flare can accommodate increased flow by an increase in diameter as well as by an increase in height. With the enclosed design, both the burner and its controls are at ground level, and therefore the cost of maintaining the enclosed flare does not change with its size.

IV. VERIFIABILITY OF DESTRUCTION OF GREENHOUSE GASES

The economics of burning gob gas in flares may benefit from revenues derived from the sale of carbon credits generated by the destruction of methane, a greenhouse gas (GHG). One of the potential drawbacks of the open flare (as compared with the enclosed design) is that it is more difficult to field test its methane destruction efficiency and thus verify the extent of its GHG mitigation success. To qualify for carbon credits, the destruction of coal mine methane (CMM) must be verifiable, and the carbon credit purchaser may require a level of verification greater than that obtained from an open flare.

Flare manufacturers typically quote a 98% destruction efficiency for open flares. "Since open flares do not lend themselves to conventional emission testing techniques, only a few attempts have been made to characterize flare emissions. Recent EPA tests using propylene as flare gas indicated that efficiencies of 98% can be achieved when burning offgas with at least 11,200 kJ/m^3 (300 Btu/ft^3)".[1]

The enclosed flare can operate at temperatures in the range of 1400°F to 2000°F and can reach destruction efficiencies of 99.5% and above if operated at the higher temperatures.[2] A recent paper presented at a landfill gas conference stated that "generally, an enclosed flare can achieve a 99% destruction efficiency of total organic compounds (TOC), 1.0% greater than the 98% obtained by an open flare"[3]. In fact, tests on an enclosed flare in California found the destruction efficiency for all hydrocarbons reported as methane to be greater than 99.99%.[4]

The increased revenue from carbon credits for the enclosed flare, attributable to its higher destruction efficiency, could amount to approximately $20,000 to $40,000 per year (depending upon particulars of the credit sale). Furthermore, removing any uncertainty regarding verification of destruction levels of the open flare may be an important consideration for selecting an enclosed flare. On the other hand, since the EPA accepts the 98% destruction efficiency of an open flare for compliance with pollution regulations (e.g., at municipal solid waste landfills), it is possible that the verifying community would also accept this destructive efficiency of the open flare. A benefit of such acceptance would be that laboratory testing of emission samples would not be required.

In either the open or enclosed flare cases, however, it will be prudent for the flare operator to work with the flare equipment provider and the carbon emission reduction purchaser concerning case-specific requirements for verification of methane destruction.

V. COST OF INSTALLATION

The body of the main report (i.e., "Conceptual Design for a Coal Mine Gob Well Flare") specifies gas flows ranging from a low of 20 thousand scf per day (mscfd) to a high of 2 million scf per day (mmscfd) (14 to 1,400 scfm). Further, it is most likely that at the high gas flows high concentrations of methane (up to 100%) could be expected, but at the lower gas flow rates the methane concentration would also be lower (~20%). It also is likely that while a new gob gas well may initially produce high volumes of gas with high concentration of methane, over a period of time the volume and concentration will both decrease.

One of the biggest drawbacks of the enclosed flare is cost. Typical order of magnitude costs for a 1,400 scfm open flare and enclosed flare are given in Table 1.

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1 *Compilation of Air Pollutant Emission Factors*, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources, Chapter 13, Section 13.5 Industrial Flares. U.S. Environmental Protection Agency, Research Triangle Park, NC.

2 Telecon with Louis Kalani and Jason Cline, LFG Specialties, April 24, 2000.

3 Louis Kalani and Ray Nardelli, *Landfill Flare Gas Emissions*, SWANA 20th Landfill Gas Symposium, Monterey, California, March 25, 1996.

4 *Compliance Source Test Report,* Tulare County Resource Management Agency, Earlmart Landfill, March 20, 1998

Table 1. Installation Cost Estimate – Open Flare vs Enclosed Flare

	Open Flare	Enclosed Flare
Flare and Controls	$ 51,139	$ 129,414
Installation	$ 32,000	$ 44,000
Complete System (including engineering, finance costs, etc.)	$ 83,139	$ 173,414

VI. COST OF OPERATION

Annual operation and maintenance costs of the open and enclosed flare are shown in Table 2 below. To be conservative, it has been assumed that the flare would be moved to a new location twice per year. A study performed at one particular mine concluded that a gob well flare would require relocation approximately every 200 days, when the flow and concentration fall below the minimum acceptable level. A probable lower limit for an acceptable average flow rate and methane concentration for an enclosed flare installation would be approximately 500 scfm at 50% methane. Below this level the project would not be viable (i.e., IRR falls below 15%).

Table 2. Operation and Maintenance Cost Estimate – Open Flare vs Enclosed Flare

	Open Flare	Enclosed Flare
Monitoring	$ 7,500	$ 7,500
Maintenance	$ 3,000	$ 5,000
Moving	$ 6,000	$ 6,000
Incremental overhead	$ 1,000	$ 1,000
Total annual cost	$ 17,500	$ 19,500

VII. SUMMARY

In comparing the two flare types, there is a significant difference in equipment costs and a smaller difference in installation costs as shown in Table 1 above. The total cost of a complete installed enclosed flare system is approximately twice that of the open flare. Operation and maintenance of the enclosed flare is also marginally higher than the open flare (Table 2).

However, installing and operating an enclosed flare can still offer an acceptable cash flow for a project of this nature.

Table 3 summarizes the advantages and disadvantages of the two types of flares.

Table 3. Advantages and Disadvantages of Open and Enclosed Flares.

Open (Utility) Flare

Advantages	Disadvantages
• Lower cost • Simple in design and installation • Portable • Lower maintenance • GHG destruction efficiency possibly accepted without sampling & analysis	• Visible Flame • Flameouts possible in windy conditions • Possible public and industry objections to visible flame • Less desirable for larger flows • Slightly lower certainty of combustion • GHG destruction efficiency may be questioned

Enclosed Flare (Thermal Oxidizer Flare)

Advantages	Disadvantages
• No visible flame • More acceptable for larger flows • Sampling assures verifiability of GHG destruction • Good burner/flame control	• Higher overall cost • Less portable • Sampling & analysis to verify GHG destruction efficiency would increase operational cost • Increased maintenance requirements

For illustrative purposes, consider an average gas flow rate over a one-year period of 1,000 scfm with a methane concentration of 65%. A cash flow analysis of an enclosed flare installation sized to accommodate the upper bound gas flow of 1,400 scfm and destroying 1,000 scfm on average (see Table 4) demonstrates that an acceptable IRR is achievable under these conditions, even assuming an outright carbon credit purchase (i.e., no up-front premium or bonus payments) at a minimum carbon value of $1.00 per tonne CO_2 in year 1.

Tables 4 and 5 provide cash flow analyses for the enclosed and open flare cases. Note that these analyses use a conservative value for carbon credits and apply a straight-line inflation of 6% per year to the carbon credit value. In actuality, it is likely that the carbon credit value in the “vintage years” period of 2008 to 2012 could increase, thereby improving the economic viability of a flare project. At the present time, the carbon credit trading market is in its early stages of development, and therefore it is not possible to predict with any certainty what the value of the carbon credits will be in the future. Note also that the cash flow analyses do not reflect various ancillary costs such as sampling and analysis to verify destruction efficiency, permitting costs, legal fees, etc.

In summary, the following benefits may accrue when using an enclosed flare rather than a utility flare for flaring gob gas.

Mine Benefits

The use of a flare for the destruction of methane must be acceptable to the mining industry. The sight of a flame at the top of an open flare may meet with opposition. The enclosed flare, on the other hand, may be more readily accepted by the mining industry because the flame is not exposed.

Global Environmental Benefits

In order for carbon credits to be granted for the destruction of GHGs, the claimed reduction in GHG emissions must be verifiable to the carbon credit purchaser, and, therefore, the enclosed flare may be preferable due to the ease of testing and analyzing the exhaust gases following methane destruction. In either case, a flare operator would need to work with the equipment provider and the carbon emission reduction purchaser to resolve this issue.

GOB WELL ENCLOSED FLARE

Assumptions

Capital cost	$	173,414	
Methane (CH_4) flow to flare	mcfd	936	(1,000 scfm gas flow @ 65% CH_4)
Availability	%	95.00	
Methane destruction efficiency	%	99.950	
Conversion of CFD of CH_4 to	Tons CO_2	0.0003511	
CO2 equivalent destroyed	tonnes/yr	113,894	
Carbon credit value - 1st.yr	\$/tonne CO_2	1.00	
Carbon credit inflation/yr	%	6	
Cost annual inflation	%	3	
First year operating cost	$	13,500	
Moving costs	$	6,000	
Total operating costs	$	19,500	
Corporate capital cost	%	15	
Project term	yrs	12	
Depreciation - SL	yrs	8	
State or Local tax rate	%	9	
Fed tax rate	%	35	

SENSITIVITY ANALYSIS

	Price for CO_2 (no premium)			
	\$.50/Mt	**\$1.00/Mt**	**\$1.50/Mt**	**\$2.00/Mt**
PERCENT IRR	20%	**41%**	60%	79%
PAYBACK IN YEARS	5.04	**2.50**	1.67	1.25

Cash Flow Analysis **(000's)**

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Carbon credit		113.9	120.7	128.0	135.6	143.8	152.4	161.6	171.3	181.5	192.4	204.0	216.2
Operating costs		(19.5)	(20.1)	(20.7)	(21.3)	(21.9)	(22.6)	(23.3)	(24.0)	(24.7)	(25.4)	(26.2)	(27.0)
Depreciation		(21.7)	(21.7)	(21.7)	(21.7)	(21.7)	(21.7)	(21.7)	(21.7)	-	-	-	-
Income before taxes		73.7	81.0	88.6	96.7	105.2	114.1	123.6	133.6	165.8	177.0	188.8	201.2
State or Local tax rate		(6.6)	(7.3)	(8.0)	(8.7)	(9.5)	(10.3)	(11.1)	(12.0)	(14.9)	(15.9)	(17.0)	(18.1)
Fed Tax rate		(25.8)	(28.3)	(31.0)	(33.8)	(36.8)	(39.9)	(43.3)	(46.8)	(58.0)	(61.9)	(66.1)	(70.4)
After Tax Income		41.3	45.3	49.6	54.1	58.9	63.9	69.2	74.8	92.9	99.1	105.7	112.7
Cash Flow	**-173.414**	**63.0**	**67.0**	**71.3**	**75.8**	**80.6**	**85.6**	**90.9**	**96.5**	**92.9**	**99.1**	**105.7**	**112.7**

IRR **41%**

Cost per tonne CO2 equivalent

	1	2	3	4	5	6	7	8	9	10	11	12
Annual Ops Cost	19.5	20.1	20.7	21.3	21.9	22.6	23.3	24.0	24.7	25.4	26.2	27.0
Capital recovery	31.99	31.99	31.99	31.99	31.99	31.99	31.99	31.99	31.99	31.99	31.99	31.99
Total Annual Cost	51.49	52.08	52.68	53.30	53.94	54.60	55.28	55.97	56.69	57.43	58.20	58.98
Tons destroyed per year	113.89	113.89	113.89	113.89	113.89	113.89	113.89	113.89	113.89	113.89	113.89	113.89
Cost per ton	**\$ 0.45**	**\$ 0.46**	**\$ 0.46**	**\$ 0.47**	**\$ 0.47**	**\$ 0.48**	**\$ 0.49**	**\$ 0.49**	**\$ 0.50**	**\$ 0.50**	**\$ 0.51**	**\$ 0.52**

Payback 2.50 **yrs**

Table 4. Cash Flow Analysis - Enclosed Flare

GOB WELL OPEN FLARE

Assumptions

Capital cost	$	83,139	
Methane (CH_4) flow to flare	mcfd	936	(1,000 scfm gas flow @ 65% CH_4)
Availability	%	95.00	
Methane destruction efficiency	%	98.00	
Conversion of CFD of CH_4 to	Tons CO_2	0.0003511	
CO2 equivalent destroyed	tonnes/yr	111,672	
Carbon credit value - 1st.yr	\$/tonne CO_2	1.00	
Carbon credit inflation/yr	%	6	
Cost annual inflation	%	3	
First year operating cost	$	11,500	
Moving costs	$	6,000	
Total operating costs	$	17,500	
Corporate capital cost	%	15	
Project term	yrs	12	
Depreciation - SL	yrs	8	
State or Local tax rate	%	9	
Fed tax rate	%	35	

SENSITIVITY ANALYSIS

	Price for CO_2 (no premium)			
	\$.50/Mt	**\$1.00/Mt**	**\$1.50/Mt**	**\$2.00/Mt**
PERCENT IRR	38%	**76%**	114%	151%
PAYBACK IN YEARS	2.78	**1.30**	0.85	0.63

Cash Flow Analysis		**(000's)**											
Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Carbon credit		111.7	118.4	125.5	133.0	141.0	149.4	158.4	167.9	178.0	188.7	200.0	212.0
Operating costs		(17.5)	(18.0)	(18.6)	(19.1)	(19.7)	(20.3)	(20.9)	(21.5)	(22.2)	(22.8)	(23.5)	(24.2)
Depreciation		(10.4)	(10.4)	(10.4)	(10.4)	(10.4)	(10.4)	(10.4)	(10.4)	-	-	-	-
Income before taxes		84.8	92.0	99.5	107.5	115.9	124.8	134.1	144.0	164.8	175.8	187.5	199.8
State or Local tax rate		(7.6)	(8.3)	(9.0)	(9.7)	(10.4)	(11.2)	(12.1)	(13.0)	(14.8)	(15.8)	(16.9)	(18.0)
Fed Tax rate		(29.7)	(32.2)	(34.8)	(37.6)	(40.6)	(43.7)	(46.9)	(50.4)	(57.7)	(61.5)	(65.6)	(69.9)
After Tax Income		47.5	51.5	55.7	60.2	64.9	69.9	75.1	80.6	92.3	98.5	105.0	111.9
Cash Flow	**-83.139**	**57.9**	**61.9**	**66.1**	**70.6**	**75.3**	**80.3**	**85.5**	**91.0**	**92.3**	**98.5**	**105.0**	**111.9**

IRR **76%**

Cost per tonne CO2 equivalent

	1	2	3	4	5	6	7	8	9	10	11	12
Annual Ops Cost	17.5	18.0	18.6	19.1	19.7	20.3	20.9	21.5	22.2	22.8	23.5	24.2
Capital recovery	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34	15.34
Total Annual Cost	32.84	33.36	33.90	34.46	35.03	35.62	36.23	36.86	37.51	38.17	38.86	39.56
Tons destroyed per year	111.67	111.67	111.67	111.67	111.67	111.67	111.67	111.67	111.67	111.67	111.67	111.67
Cost per ton	**\$ 0.29**	**\$ 0.30**	**\$ 0.30**	**\$ 0.31**	**\$ 0.31**	**\$ 0.32**	**\$ 0.32**	**\$ 0.33**	**\$ 0.34**	**\$ 0.34**	**\$ 0.35**	**\$ 0.35**

Payback **1.30** **yrs**

Table 5. Cash Flow Analysis - Open Flare