Comments on
2010 TCEQ Flare Study Project Final Report [D R A F T]
The University of Texas at Austin
The Center for Energy and Environmental Resources
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Submitted by
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Severely limited scope

This study project, although exceedingly well executed by TCEQ's University of Texas contractor and numerous subcontractors; and despite the project's $2-million plus cost and year-plus planning span; and like all the other experimental studies that have been competently conducted over the past decades, this study project was necessarily ***severely limited in its scope of parametric variation***.

Commenting on the TCEQ Flare Study, one member of the Technical Review Panel hit the nail on the head when he advised, *"Remove 'comprehensive' from title of study."* [1] I could hardly agree more. We have learned over the past decades that "comprehensive" is a tall order. "Comprehensive" is hard to achieve *ever* experimentally and particularly so when mucking about with full-scale combustion systems in the field.

The reader of these comments should understand that this is not so much a criticism as it is merely a simple recognition of the plain facts proven over and over again during the past decades; *viz.,* that a "comprehensive" experimental full-scale flare emissions study project is a practical impossibility; and, thus, that regulatory generalization is doomed at best to be an unrequited and abandoned dream or, worse, to be a misguided broad generalization carried out anyway.

Misguided broad generalization

The consequence of the foregoing perhaps inconvenient truth is that in the sequel there inevitably will arise misguided and ill-conceived attempts to generalize the results of this study project for regulatory purposes.

To the credit of the principal investigator and his staff, care has assiduously been taken not to make this mistake in the draft report, although there is an ominous reference to future analyses; *viz.,* "The Study team recognizes that follow-on work with the data collected in this project would be valuable and looks forward to the opportunity to participate in those analyses." [2]

My suggestion? Beware ill-advised broad generalizations and unwarranted extrapolations patently beyond the reach of the experimental data variation relating to, for example,

- *other* flare designs not tested *(of which there are many)*,
- *other* combinations of flare head exit velocity and diameter not tested *(of which there are many)*,
- *other* combinations of pilot design, heat release, number and location not tested *(of which there are many)*,

[1] TCEQ Flare Study Technical Review Panel Comment Summary, p.7; Link: http://www.tceq.texas.gov/assets/public/implementation/air/rules/Flare/2011.05.24_Summary%20of%20Comments_FNL.pdf
[2] TCEQ draft study report, Sec. 1.0 Introduction, p.40; Link: http://www.tceq.texas.gov/assets/public/implementation/air/rules/Flare/TCEQ2010FlareStudyDraftFinalReport.pdf

- *other* operating conditions not tested *(of which there are many)*,
- *other* flare gas compositions not tested *(of which there are many)*,
    - not least *hydrogen*-bearing mixtures which are well-known and recognized even in 40CFR60.18 to behave entirely differently, [3] [4] [5]
    - and including the markedly differing effects of dilution by nitrogen vs. carbon dioxide,
- and certainly the variable effect of wind, well-known to be significant but necessarily excluded from this study.

Just to make that rather important point, one has only to make reference to the 25 year old warnings of the principal investigator and others regarding unwise generalization of the data produced by the archival and archetypal but similarly severely limited USEPA mid-1980's studies on which 40CFR60.18 was based; for example,

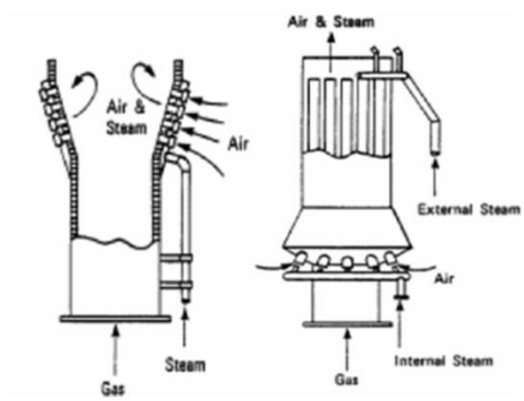
> "All conclusions are based on the data of this study and are **limited to the head geometries, gases and variables examined**." [6] *[**emphasis** mine]*;

and reflect on how well the subsequent ill-advised broad generalization worked out 25 years ago in the case of the formulation of the now broadly discredited 40CFR60.18.

My suggestion? Beware making that mistake again.

Design differences critical

Just to make the point, consider these two flare heads that employ entirely different modes of steam-assisted combustion zone aeration. One would hardly expect these two flare heads to behave "similarly" with respect, for example, to CE, DE or DRE, would one?



One has only to consider the observed sensitivity of CEs and DREs that is attributed in the TCEQ study project draft report merely to minor variations in the modes of center and upper steam usage in the only steam-assisted flare head tested!

Then, of course, there are *staged* elevated flares, *annular* elevated flare heads, *multipoint* elevated flare heads, *high-pressure sonic* elevated flare heads, *low-pressure* steam nozzles, *high-pressure* sonic steam nozzles, *etc. and so forth,* all of which would be expected to behave differently one from another.

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[3] § 60.18(c)(3)(1)(A) General control device and work practice requirements. p.91; Link: http://edocket.access.gpo.gov/cfr_2010/julqtr/pdf/40cfr60.18.pdf

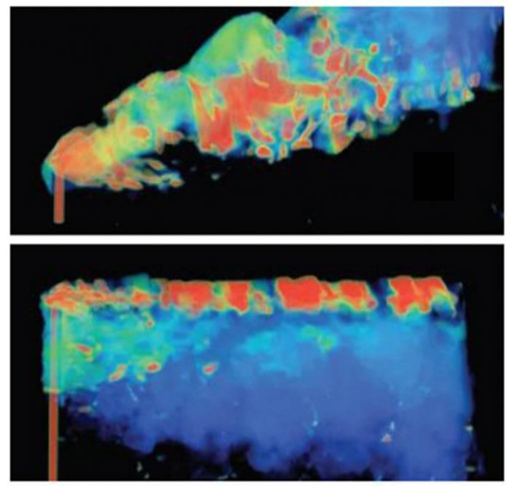
[4] Demonstration of Hydrogen Use in Steam- and Air-Assisted Flares, Alexis McKittrick, Combustion R&D, Praxair, Inc., June 9, 2009; Link: http://www.afrc.net/assets/fordownload/flareforum/2009_boston/demonstration_of_hydrogen_use_in_steam-and_air-assisted_fla.pdf

[5] Flame Stability Limits and Hydrocarbon Destruction Efficiencies of Flares Burning Waste Streams Containing Hydrogen and Inert Gases; Peter M. Walsh, GE – Energy and Environmental Research Corporation, et al, November 6, 2002; Link: http://www.afrc.net/assets/fordownload/flareforum/2002_houston/flame_stability_limits_and_hydrocarbon_destruction_efficienc.pdf

[6] Evaluation of the Efficiency of Industrial Flares: Test Results, May 1984, J.H. Pohl, *et al,* p.2-13, Link: http://www.tceq.state.tx.us/assets/public/implementation/air/rules/Flare/Resource_2.pdf

Wind differences critical

And just to make the point about the importance of accounting for wind variation and to appreciate the variable and potentially severely disruptive effect of crosswinds, particularly at the extreme turn down conditions of the TCEQ Flare Study that were necessitated by the practical limitations of carrying out full-scale experiments at grade, one has only to look at the visualization of two different flare plumes shown at the right. [7]



Volume rendered images of a large eddy simulation (LES) of a flare operating under two different crosswind conditions. Hot colors (red) represent high combustion inefficiency.

Courtesy Phil Smith, The Institute for Clean & Secure Energy, The University of Utah

These are volume rendered images of a large eddy simulation (LES) of a flare operating under two different crosswind conditions, lower in the top view resulting in a largely buoyant flame, higher in the bottom view resulting in a wake-stabilized flame. The hot colors (red) represent low combustion efficiency or, equivalently, "... high combustion inefficiency."

The marked inhomogeneous distribution of local CEs in flare plumes raises a question that troubles some of us "point-and-shoot" fans. Where do you aim to get an accurate measure of the *overall* combustion efficiency as a measure of overall emission control performance? I'd give worlds to know.

"Multiple DREs" -- and CEs, too*!*

The draft report makes a big point about finding multiple destruction and removal efficiencies ("DREs") for propylene in the propylene-firing tests while in point of fact multiple destruction efficiencies ("DEs") [8] and combustion efficiencies ("CEs") have been the bane of flare emissions researchers for decades. Been there, done that; lots and for a long time!

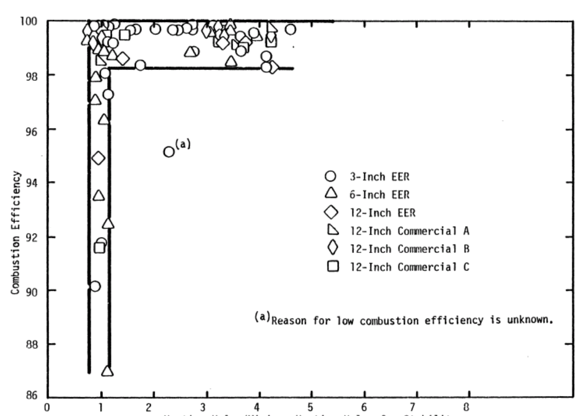


Figure 2-4. Combustion efficiency near the lower limits of flame stability.(b)

(b) Based on flares burning propane/nitrogen mixtures with no pilot flame.

Multiple CEs and DEs and, more fashionably today, "DREs," occur when the assumed governing parameter [9] against which data is plotted fails to collapse the data. Classic examples, not surprisingly looking much like the plots in the draft report, can be

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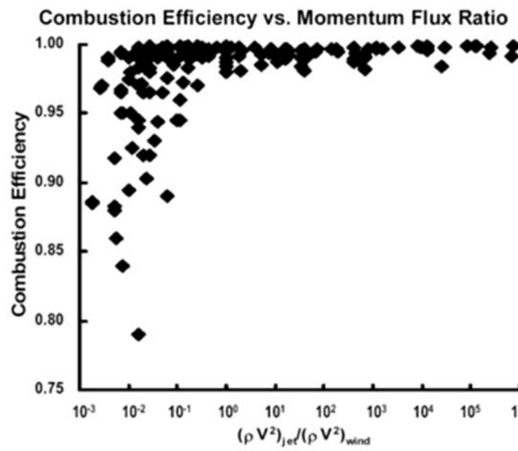
[7] Source: http://www.flaresimulations.org/index.jsp

[8] Referring to the concentration of a particular inlet species remaining in the plume following completion of combustion.

[9] Often the long lusted after but to date elusive universal correlating parameter.

found for example in Pohl(84) [10] and Seebold(04) [11] as shown in the two charts in this section.



Quoting the draft report text.

> *"It can be seen from Figures ES-4a and ES-4b that in this range of S/VG ratios there can be **multiple DREs**. This is due in part to the fact that, in this range of S/VG ratios, steam added at the center has a different effect on DRE than steam added at the upper nozzles."* [12]

Again,

> *"Figures ES-6a and ES-6b show DRE (propylene) versus S/VG ratio and CE versus S/VG ratio, respectively, for all of tests series S5 and S6 on one graph. Figures ES-7a and ES-7b are the same graphs focusing on the range DRE (propylene) ≥ 84%. It can be seen from Figures ES-7a and ES-7b that in this range of S/VG ratios there can be **multiple DREs."*** [13]

And again,

> *"Figures ES-9b and ES-10b focus on the range of DRE ≥ 84 % to better examine the relationship between these two parameters. There can be **multiple DREs** for CZG NHVs up to at least 250 Btu/scf and perhaps as high as 300 Btu/scf. Once again, this is due in part to the fact that, in this range of S/VG ratios, steam added at the center has a different effect on DRE than steam added at the upper nozzles."* [14]

"... *in part* ..." indeed! More comprehensively, the multiple DREs simply reflect the fact that the long lusted after "best operating practice envelope" is an exceedingly complex multivariate multiparameter hypersurface in which "CE" and "DE" and "DRE" are simply three amongst a legion of governing and dependent parameters.

Reacting jet hydrocarbon gaseous external combustion is well-known to be exceedingly robust, exhibiting high CEs, DEs and DREs. [15] In the industrial flare world these flares are called "jetting" or "jet-assisted" or "high-pressure" and, standing tall and proud even in a high wind, they look like this. Flares like the one pictured here arise during major plant upsets such as total loss of electrical power. They are intended to be <u>*emergency*</u> flares.

By comparison, used as low-flow emissions control devices, the necessarily monster flare burners that rarely if ever operate at anything like their design emergency capacities look like the picture on the next page that is

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[10] Evaluation of the Efficiency of Industrial Flares: Test Results, May 1984, J.H. Pohl, *et al,* p.2-14, Link: http://www.tceq.state.tx.us/assets/public/implementation/air/rules/Flare/Resource_2.pdf

[11] Practical Implications of Prior Research on Today's Outstanding Flare Emissions Questions and a Research Program to Answer Them, AFRC Int'l Symposium, Maui, Hawaii, Oct 2004, J.G. Seebold, *et al,* p.4, Link: http://www.afrc.net/assets/fordownload/flareforum/2004_maui/practical_implications_of_prior_research_on_todays_outstand.pdf

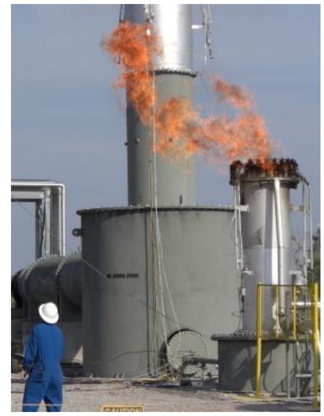
[12] 2010 TCEQ Flare Study Project Final Report [D R A F T], p.7; Link: http://www.tceq.texas.gov/assets/public/implementation/air/rules/Flare/TCEQ2010FlareStudyDraftFinalReport.pdf

[13] 2010 TCEQ Flare Study Project Final Report [D R A F T], p.12; Link: http://www.tceq.texas.gov/assets/public/implementation/air/rules/Flare/TCEQ2010FlareStudyDraftFinalReport.pdf

[14] 2010 TCEQ Flare Study Project Final Report [D R A F T], p.12; Link: http://www.tceq.texas.gov/assets/public/implementation/air/rules/Flare/TCEQ2010FlareStudyDraftFinalReport.pdf

[15] Products of incomplete combustion from petroleum, petrochemical & chemical sector process heaters and industrial boilers, J.G. Seebold & R.T. Waibel, 10th PIC Congress, Ischia, Italy, June 2007; Available by request: jim.seebold@earthlink.net

taken from the TCEQ flare study project draft report. Regrettably, both the difference in and the plainly expectable compromises of CEs, DEs and DREs are painfully obvious just from the appearance of the reaction zone.



One has to wonder if the wimpy flow rates of the normally idling emergency flares in the Greater Houston region, like those tested in the TCEQ flare study project, contribute total yearly HRVOC emissions that have any impact whatsoever on ozone exceedences in the region.

Nobody has ever looked at that probably not least because some don't want to look; and, for sure, the collection of wimpy flow rate, normally idling emergency flares contributes nothing like the total HRVOC emissions that emerge 24/7/365 from the billions of Btu/hr that are consumed in process heating in the region's oil refineries, petrochemical and chemical plants.

Relatedly, it may be significant to observe that more recently the environmental lobby have been much more concerned, perhaps rightly so, about major ***emergency*** flare releases that have occurred in consonance with episodic ozone exceedences. [16] [17] It is important to note, however, that whether or not ***any*** observed consonance of a major local flare release is causal of or merely coincidental with a general regional episodic ozone exceedence has never been established by photochemical modeling or by any other scientifically reliable means.

Follow-up on Phase I Conclusions & Recommendations*?*

It seems to be missing from the TCEQ flare study project draft report. A brief recount of both the Phase I report and follow-up on its conclusions and recommendations would be useful, at least to those who have followed this effort over the years since 2004 and before.

Exceedingly well-founded theoretically, PFTIR certainly has the potential to become an excellent and much-needed remote measurement and quantification "point-and-shoot" technology. But until now, at least and despite its perhaps premature wide-spread use, PFTIR remained ***unproven*** in blind-validation trials against well-established regulatory-agency-approved extractive sampling protocols. In fact, despite the fact that the final report spins the results quite positively, in TCEQ's well-executed 2004 "Phase I" trials PFTIR ***failed*** blind-validation. [18]

The TCEQ Phase I tests utilized a hot gas generator to generate a plume that was seeded with known target compounds, the concentrations of which were verified by extractive sampling. PFTIR had a good oblique view of the plume. Nevertheless, PFTIR failed blind-validation. Considerable differences were observed between the known target compound concentrations and those obtained by PRTIR. To its credit, the report acknowledged that the differences "... are not well understood."

The Phase I report asserted that that an "... improved detector design should help improve the overall sensitivity for C_3+ and THC." It is unclear from reading the present TCEQ flare study project draft report whether or not that improvement was actually accomplished. If it was, the report should say so. If it was not, the report should say why not.

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[16] Links: http://www.environmentalintegrity.org/law_library/documents/FactSheet-CPChemSettlement.doc; http://www.environmentalintegrity.org/law_library/documents/PressRelease-CPChemSettlement.doc

[17] Links: http://www.environmentalintegrity.org/law_library/documents/FactSheet-ShellSettlement.doc http://www.environmentalintegrity.org/law_library/documents/PressRelease-ShellSettlement.doc

[18] TCEQ PFTIR Phase I Testing Final Report, URS(2004). Link http://www.tceq.state.tx.us/assets/public/implementation/air/am/contracts/reports/oth/Passive_FTIR_PhaseI_Flare_Testing_r.pdf

To what extent did 2004's Phase I recommended improvements enhance 2010's Phase II PFTIR performance? Perhaps it would be useful to explain that in the TCEQ flare study project final report.

Particularly to its credit notwithstanding the overall positive spin, the Phase I report acknowledged that "... more effort is needed to understand these differences in results _before attempting further field tests_." *[emphasis mine]* Was that done? If it was, the TCEQ flare study project final report should elucidate and state the conclusions. If it was not done, the report should say why not.

The TCEQ Phase I PFTIR trials also included a limited test of an elevated flare. The report confessed that the "... flare experiment provides valuable information for assessing logistical difficulties that might be encountered during field measurement campaigns." The prescient prediction of "... logistical difficulties ..." has certainly come true, in spades, in USDOJ/USEPA Enforcement Division Consent Decree field trials that have recently been completed or are currently under way.

The TCEQ Phase I PFTIR report concluded that "... PFTIR _*appears*_ to be a _*potentially*_ viable method _*warranting further study*_ based on the Phase I Study results ..." and that "... a second campaign should be conducted ... to _*validate*_ the PFTIR method." *[emphasis mine}* The TCEQ Phase I PFTIR report concluded with three "Path Forward Recommendations;" *viz.,*

- "One series of tests would be conducted on the plume generator to _*validate*_ the effectiveness of the proposed software and hardware modifications." *[emphasis mine}*
- "A second series of tests would then be performed on a well instrumented ground flare to _*demonstrate*_ the robustness of the PFTIR method to accurately characterize emissions from flare plumes." *[emphasis mine}*
- ***"**_After_ method confirmation*, a series of field tests on actual flare systems could then be scheduled." *[emphasis mine}*

That was then (2004) and this is now (2011). The second validation campaign was completed in September 2010 and appears to have taken a welcome big step forward toward proving PFTIR.

But is PFTIR really ready for reliable, robust field use? One has to wonder. PFTIR has been used recently in USDOJ/USEPA Enforcement Division Consent Decree field trials, sometimes producing scattered, uncertain, ambiguous and inexplicable results.

An objective, unbiased assessment of PFTIR's suitability for regulatory and enforcement uses would be a great addition to the TCEQ flare study project final report.

Plume composition "mystery" resolved*?*

Perhaps. But the "Table ES-1 List of Hydrocarbons Typically Found in Plume during Propylene Flare Tests [1-6]" found on page 27 of the TCEQ flare study project draft final report is hardly a revelation.

Burn even a fuel as simple as laboratory-grade methane pure as the drifted snow, get in the plume traces of virtually all of the approximately 100 hydrocarbon intermediates. Got a problem with that? Take it up with God.

For example, in the 14-year-old now-famous "PERF" study of gaseous hydrocarbon external combustion,[19] 43 hydrocarbon species were detected and quantified; *viz.,*

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[19] The Origin and Fate of Toxic Combustion Byproducts in Refinery Heaters: Research to Enable Efficient Compliance with the Clean Air Act, Petroleum Environmental Research Forum Project 92-19, Final Report, August 1997; Links:http://www.epa.gov/ttn/atw/iccr/dirss/perfrept.pdf ; http://www.epa.gov/ttnatw01/iccr/dirss/perfrept.pdf;

ALDEHYDES: Acetaldehyde, Formaldehyde[*], Acrolein, Acetone, Propanal, Methylethylketone, Benzaldehyde, Isopentanal, Pentanal, o-Tolualdehyde, m-Tolualdehyde, p-Tolualdehyde, Hexanal

LIGHT VOLATILE ORGANIC COMPOUNDS: Acetylene, Ethylene[**], Ethane, Propyne, Propane, Propylene[**], 1,3-Butadiene[**], 1-Butene, cis-2-Butene, Butane

HEAVY VOLATILE ORGANIC COMPOUNDS: 1-Butene, Benzene*, Toluene, Hexane, mp-Xylene, Heptane, Octane

POLYCYCLIC AROMATIC HYDROCARBONS: Naphthalene, Acenapthylene, Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(b)fluoranthene, Benzo(e)pyrene, Indeno(1,2,3- cd)pyrene, Benzo(g,h,i)perylene, Benzo(a)pyrene*, Coronene

The PERF study required detection limits as low as 100 ppq [20] for the PAHs. Lower detection limits would have produced even more detections in all classes.

That many more compounds were not detected in the TCEQ flare study presumably simply reflects the fact that the measurement contractors employed sample trains with analytical detection limits that were inadequately low to detect more of the hydrocarbon species that were surely there for the detecting, if you are good enough at detecting.

A flame is an amazing reactor – a hot, rich, effectively dissociated well-mixed reaction zone in which the role of inlet gas is simply to provide its elemental constituents to the flame reactor. The external combustion of gaseous hydrocarbon mixtures by any means, including flaring, literally manufactures and subsequently emits to the atmosphere traces of all possible molecular combinations of the elemental constituents present either in the fuel or in the air including ozone precursor highly reactive volatile organic compounds (HRVOCs) and carcinogenic hazardous air pollutants (HAPs).

So it is hardly a revelation that burning even methane pure as the drifted snow and in the best possible well-mixed way produces trace emissions of ethylene, propylene, butadiene, and all the other highly reactive volatile organics; formaldehyde, benzene and benzo(a)pyrene, the class-archetypal hazardous air pollutant carcinogens; and all the other hydrocarbon compounds in the gas phase up through 300 mw coronene.

In short, the gaseous hydrocarbon external combustion reaction zone behaves like an effectively dissociated highly reactive elemental soup in which all possible combinations of the inlet elemental reactants are formed in accordance with their chemical kinetic propensity to do so; and, there being no zero in nature, traces of all possible molecules remain in the flue gas for the detection if you are good enough at the detecting.

Smoking flares most efficient*?!*

A couple of years ago I was asked by a plant operator how *"... the incipient smoke point ..."* might be related to the point of highest combustion efficiency in a steam-assisted elevated flare.

"Hmmm ...." said I. Frankly, I was at first taken aback by the inquiry.

I asked myself, *"When have we lately or 30 years ago or at any time in between actually defined or even really taken an interest in something called an "incipient smoke point?"*

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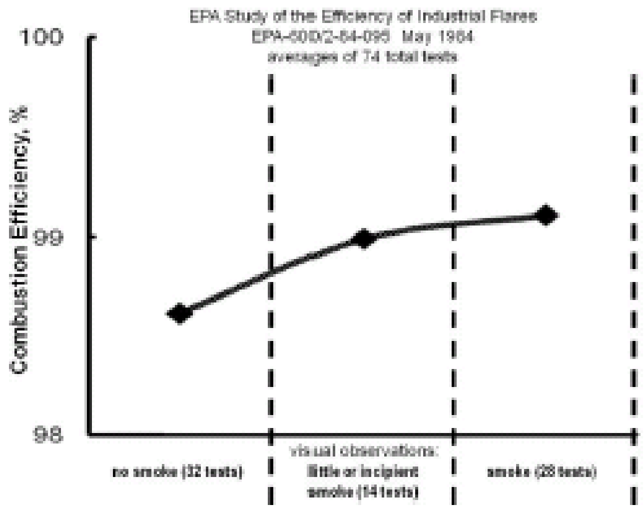
[*] Class archetypal carcinogen

[**] HRVOC

[20] Yes, parts per ***quadrillion***!

But upon reflection it seemed to me to be a reasonable perhaps unquantified but certainly sensible concept that we perhaps *should* have been confronting more than we have. It seemed to me that we ought to be able to come up with data and charts from prior studies, particularly the landmark mid-80s EPA study with which I was so closely associated, that would at least go some way toward identifying and quantifying the concept of an "incipient smoke point."

In that mid-80s study, an interesting and related overarching fact emerged; *viz.,* out of a total of 74 tests in which 32 were observed to be "clear," 14 were observed to be "incipiently smoking" and 28 were observed to be "smoking," the average combustion efficiencies were 98.61%, 98.99% and 99.11% respectively. Yes, the smoking flares were slightly *more* efficient!



While that fact distresses some it is, nonetheless, incontestable and lends credence, it seems to me, to the concept of trying to keep flare operation near the incipient smoke point to ensure at least *near* optimal combustion efficiency. In addition to the averaged results highlighted above, the results are also conveniently summarized in this figure.

I emphasize *"near"* optimal because the landmark mid-80s EPA study data actually suggests that for the *best* combustion efficiency you should run at least slightly smoking all the time! That would not be wise, of course, because it is patently illegal in accordance with the USEPA's General Requirements for Flares at 40CRF60.18 and the rules of most local jurisdictions.

Nevertheless, that a smoking flare is often the most efficient flare remains a perhaps inconvenient truth. Smoking flares are *not* inefficient, only illegal.

It is not surprising and perhaps worth mentioning here that the results of the other landmark study of the mid-80s that was carried out by the Chemical Manufacturers Association and reported in Hydrocarbon Processing, October 1983, pp.78-80, produced similar results.

And now so does the 2010 TCEQ flare study. Thus it seems to me that the efficacy of the concept of introducing a control system that would keep flare operation just above the incipient smoke point to ensure high near-optimal combustion efficiency is amply supported by the landmark studies of both past and present.

That's easier said than done, however. Regrettably I am aware of quite a number of failed attempts at inventing and implementing just such a control system. Been there, done that.

My advice? Keep on trying ... *somebody* is going to make it work!

Understanding steam injection

The role of steam injection in industrial flaring is to suppress smoke mainly by augmenting combustion zone aeration. There is a little water gas shift and a little cooling to suppress cracking. But it's mainly steam-motivated aeration and mixing.

Up to a point, steam injection not only suppresses smoke generation but also enhances the combustion efficiencies of industrial flares. But overdoing it by so-called "over-steaming" can reduce combustion efficiencies by reaction quenching and, eventually, reaction snuffing. One has to wonder if there is any hope at all of satisfactorily resolving *experimentally* (*i.e.,* by *field testing*) today's concerns about the effect of over-steaming on the combustion efficiency of steam-assisted industrial flares.

The steam assist nozzles arrayed around the circumference of a simple flare tip must first entrain great volumes of air and then project the resulting steam/air jets into the flare combustion zone thus enhancing aeration and mixing. It seems reasonable to suppose that, *everything else held constant,* as the flare tip diameter increases it becomes harder and harder for the steam/air jets to penetrate the combustion zone. That is why, as the tip diameter increases, more and more steam is required to provide the same enhancement of aeration.

The difficulty in flare combustion efficiency testing emerges from the *"everything else held constant"* caveat. For a given proprietary steam-assisted flare tip design tested in quiescent wind conditions, critical determinants of combustion efficiency are fuel composition, [21] tip velocity and steam-to-fuel mass ratio. While other factors like steam pressure (low-pressure vs. sonic nozzles) have an influence, too, those factors have long been recognized as important.

For a given proprietary steam-assisted flare tip design tested in quiescent wind conditions, the prudent researcher who is interested in the effect of steam injection on the combustion efficiency of a particular fuel composition would systematically vary the steam-to-fuel mass ratio for each of several flare tips in a homologous diameter sequence (*e.g.,* 3"D, 6"D; 12"D; 24"D and 48"D). That was done in a very limited way in the EPA(84,85,86) [22] testing on a fuel mixture of 56% propane in nitrogen.

To understand the effect of oversteaming on industrial flare combustion efficiency performance, experimental researchers will have to investigate at least a full range of proprietary designs, a full range of ambient wind conditions, a full range of fuel compositions, and a full range of tip velocities, all held constant whilst varying the steam-to-fuel ratio. *Good luck and God speed!*

My suggestion? Spend your money on simulation science, the fully chemical kinetically enabled large eddy simulations that are today being carried out on massively parallel multiple processor arrays. And combine that with a lot of testing with advanced diagnostics. Forget the thus far failed, decade's long quest for the *"Holy Grail"* of experimental flare combustion efficiency research, the magic universal combustion efficiency correlating parameter. *Let it be the simulation **coupled** with advanced diagnostics experiments!* You've got a long way to go. But that way you might get done in your lifetime.

James G. (Jim) Seebold served as Technical Advisor for the mid-1980s USEPA Evaluation of the Efficiency of Industrial Flares. He conceived and led the Petroleum Environmental Research Forum's 4-year $7-million 20-participant industry, government, university collaboration that quantified the speciated trace emissions from gaseous hydrocarbon external combustion,[23] widely acknowledged as one of the most successful collaborations ever; was the Founding Principal Investigator of the International Flare Consortium that has just completed its work; has organized and will keynote an Industrial Flares Colloquium to be held September 18-21 in Houston in conjunction with the American Flame Research Committee (AFRC) Annual Meeting to which all readers are cordially invited. [24]

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[21] *N.B.,* Importantly, ***NOT*** merely Btu/scf*!*

[22] Pohl, J.H., R. Payne and J. Lee, "Evaluation of the Efficiency of Industrial Flares: Test Results," EPA-600/2-84-095, May 1984; Pohl, J.H. and N.R. Soelberg, "Evaluation of the Efficiency of Industrial Flares: Flare Head Design and Gas Composition," EPA-600/2-85-106, Sept 1985; Pohl, J.H. and N.R. Soelberg, "Evaluation of the Efficiency of Industrial Flares: H_2S Gas Mixtures and Pilot Assisted Flares," EPA-600 /2-86-080, Sept 1986

[23] The Origin and Fate of Toxic Combustion Byproducts in Refinery Heaters: Research to Enable Efficient Compliance with the Clean Air Act, Petroleum Environmental Research Forum Project 92-19, Final Report, August 1997; Links:http://www.epa.gov/ttn/atw/iccr/dirss/perfrept.pdf ; http://www.epa.gov/ttnatw01/iccr/dirss/perfrept.pdf;

[24] Announcement - AFRC Industrial Flares Colloquium, Houston, TX, Sept 18-21, 2011;
Link: http://home.earthlink.net/~jim.seebold/id21.html