Technical Study on the Combustion Efficiency of American Welltest Incinerators
Part 1: Basics of Combustion Efficiency

Abstract

American Welltest Incinerators are designed for the purpose of removing or converting the hydrocarbon compounds typically found in the Petrochemical Industry Welltest and Vent Gas applications. These hydrocarbons are converted in to a primarily benign flue gas exhaust composed of CO_2, H_2O, N_2, and air. (Some SO_2 will be produced if used in Sour Gas applications.) One of the primary components and most prevalent compounds found in Welltest and Vent Gas applications is Methane. The global warming potential of methane is more than 20 times greater than that of $C0_2$. American Welltest Incinerators are able to convert virtually 100% of the methane gas to CO_2, thereby significantly reducing the contribution to greenhouse gas emissions.

In the Petrochemical Industry the terms “Incinerator” and “Thermal Oxidizer” are often used synonymously. It would be more technically correct to call the AWI units Thermal Oxidizers, but the term incinerator is more common in the industry. One of the reasons for this is that true incinerators and thermal oxidizers both *control* the same three key parameters required for efficient combustion. These are **T**ime, **T**emperature, and **T**urbulence. The AWI design provides highly efficient conversion and dispersion of the products of combustion due to high operating temperatures, longer residence times at these elevated temperatures, increased stack velocities from the forced draft system which generates the turbulence, and the 40 foot exit elevation.

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The Theory Behind American Welltest Incinerator Efficiency

As mentioned above, in order to maximize combustion efficiency, a combustion device must maximize all 3 T's of Combustion: **T**ime, **T**emperature, and **T**urbulence. This is how AWI units are able to achieve this.

1) Time

Time, in terms of combustion theory, refers to "residence time". This is the amount of time at which the elevated temperature of combustion is maintained and controlled within the process. In order to achieve maximum combustion efficiency, the combustion process is elevated to the required temperature and then that temperature is maintained for a specified amount of time. This ensures sufficient time for the "destruction" of the complex Hydrogen-Carbon compounds present in the gas, and then the recombining of these elements with oxygen (oxidation) in to H_20 and CO_2. Residence time is technically defined as the time from the last point of introduction of air to the process to the point of discharge of the flue gas from the vessel.

In the American Welltest Incinerators the combustion process and introduction of air all takes place at the base of the incinerator vessel. This provides the entire length and volume of the incinerator vessel to generate sufficient residence time for the destruction of the hydrocarbons and the oxidizing of these in to benign flue gas compounds.

2) Temperature

Temperature refers to the minimum elevated temperature required for the destruction of the hydrogen-carbon bonds of the various hydrocarbon compounds present and then the recombining the liberated hydrogen and carbon atoms with oxygen (oxidation). In the AWI units, one of the keys to the conversion and high combustion efficiency is the ability to precisely control this temperature. This is achieved through the measurement of the temperature within the combustion chamber vessel with a thermocouple, and using a temperature controller in the control panel to modulate the amount of combustion and excess air introduced through the primary and secondary air fans. It is important that no "fugitive" outside air interferes with this process and lowers the temperature before the oxidation process is complete. The enclosed chamber and finely tuned temperature control loop ensure the proper temperature is maintained within the American Welltest Incinerators.

3) Turbulence

Turbulence refers to the turbulent mixing of the hydrocarbon compounds in the gas with the available oxygen present in the (forced draft) air at an elevated temperature. This turbulent mixing of the waste gas with the oxygen in the air provides a more efficient combustion (oxidation) process as there are more "collisions" between the hydrogen or carbon atoms and the oxygen atoms. These turbulent mixing effects are most effective directly at the point of combustion, or more specifically right in the burner assembly area. The process continues until either all hydrogen and carbon is consumed, or all available oxygen is consumed.

Therefore, for a well-designed, efficient incinerator to achieve its purpose it must not only utilize the Three **T**'s of combustion, but apply them in a controlled fashion at the proper time and location. This is the basis of the American Welltest Incinerator design.

The 3 T's of Combustion – American Welltest Incinerators vs. Flaring or Alternative Combustion Processes

Flares

An industrial flare assembly is generally regarded as an open air diffusion combustion process. The combustion process occurs in the open air and is subjected to ambient environmental conditions. It is common to observe that the black smoke from a flare stack is generally more visible on windy days. The reason is basically two fold; a) the open air diffusion flame at the top of the flare stack is being cooled immediately by the ambient air and wind and therefore the temperature is reduced, and b) the open air diffusion flame is also being elongated by the ambient wind. Not only is the theoretical flame temperature been reduced by exposure to the ambient air, but the overall flame temperature is also cooler as the flame size at the top of the flare stack is now longer and narrower, providing greater surface area for cooling. The flame area has greater exposure to the ambient environmental conditions as the flame surface area has been increased, and thus cooling is occurring at a higher rate.

Once the flame temperature has been reduced sufficiently, combustion ceases and any unburned hydrocarbons become visible as black smoke. Flare manufacturers have been working on various flare tips over the years to increase turbulent mixing. However, in most cases the turbulence in a flare tip is limited to the speed and intensity of the gas moving through the flare tip. In some cases at larger scale facilities, air and steam have been used to increase turbulent mixing at the flare tip to increase combustion efficiency. But time and temperature effects continue to present a challenge for flares.

Others

Other combustion devices are also used with varying degrees of success. The typical shortcomings involve the inability to control one (or more) of the 3 T's. They either lack precise temperature control, lack the ability to generate aggressive turbulence for proper mixing of air and gas, or lack sufficient residence time after the last point of air addition to ensure completion of the combustion process.

Incinerator

An Incinerator is a combustion device designed to convert compounds at a very high efficiency rate. In the AWI design the “3 T’s of Combustion” have all been considered.

The AWI incinerator is an enclosed chamber that is lined with high efficiency thermal insulating ceramic fibre lining in order to maintain internal temperatures. Temperatures inside the chamber can quite often reach 1,000°C (or 1,830°F), while the exterior shell temperature is less than 50°C (or 122°F). The combustion temperature inside the incinerator is also displayed and recorded during the operation of the unit.

The AWI Incinerator has been designed with a typical minimum residence time of 0.5 seconds at maximum throughput. If the throughput is reduced the residence time increases.

The AWI Incinerator system includes a total of 42 HP in five forced draft fans to provide primary and secondary air for the combustion process throughout its operating range. The air integration has been specifically designed to provide aggressive, turbulent mixing at the burner assembly, and oxidation of the hydrocarbons in the process area. Primary air is introduced at more than 300 feet per second creating an intense turbulent mixing area vortex.

These AWI systems have been specifically designed for Well Flow backs / well completion operations. They are well-designed, efficient incinerators which achieve their purpose by utilizing the Three **T**’s of combustion, and applying them in a controlled fashion at the proper time and location.

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The Science Behind the Increased Efficiency of an American Welltest Incinerator (vs. Other Technology)

The Combustion Efficiency, or Destruction Removal Efficiency (DRE) of any compound is calculated by a formula known as the Arrhenius Law developed by Professor Svante Arrhenius. The formula is expressed as:

$$N = 1 – \exp [-V \times t \times \exp \{-E/(R \times T)\}]$$ where:

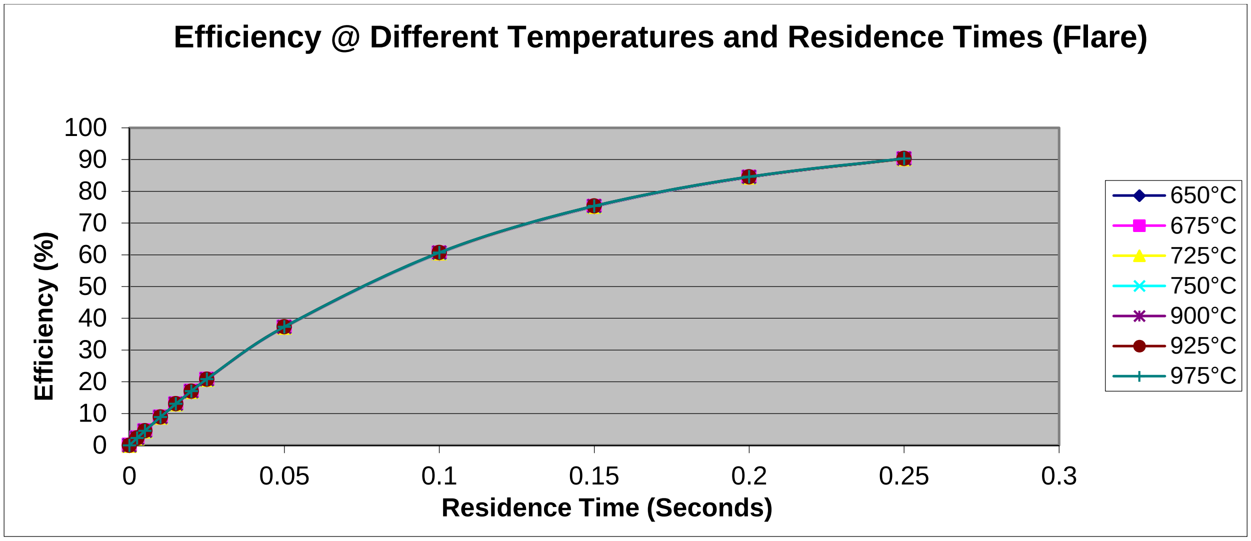
- t = time (seconds) at temperature T
- T = temperature (K)
- E = activation energy (cal/g-mole) which is specific to each compound
- R = universal gas constant (1.987 cal/g-mole-K)
- N = destruction efficiency
- V = frequency factor (sec^{-1}) also specific to each compound

The following data to demonstrate this is based on Methane Gas, which is typically one of the most common, and most prevalent gases in Welltest applications. Performing the calculations using the Activation Energy and Frequency Factor for Methane at various temperatures and residence times we can generate the following Table 1, which would be representative of a flare.

Combustion Efficiency at Various Temperatures and Residence Times (Short Residence Times Associated with Flaring)							
Time	Temperature						
T (sec)	650°C	675°C	725°C	750°C	900°C	925°C	975°C
0.25	90.1821	90.19782	90.22685	90.24029	90.30871	90.31842	90.33667
0.2	84.38238	84.40239	84.43935	84.45647	84.5437	84.5561	84.57939
0.15	75.1566	75.18047	75.2246	75.24504	75.34931	75.36414	75.39201
0.1	60.48087	60.50619	60.55301	60.57471	60.6855	60.70127	60.73092
0.05	37.13576	37.1559	37.19316	37.21044	37.29873	37.3113	37.33495
0.025	20.71303	20.72573	20.74924	20.76014	20.81586	20.82381	20.83874
0.02	16.94582	16.95647	16.97617	16.98531	17.03202	17.03867	17.05119
0.015	12.99963	13.00799	13.02347	13.03065	13.06735	13.07258	13.08242
0.01	8.865936	8.871776	8.882587	8.8876	8.913236	8.916891	8.923764
0.005	4.535837	4.538896	4.544558	4.547185	4.560614	4.562529	4.56613
0.0025	2.294236	2.295801	2.298699	2.300043	2.306916	2.307896	2.309739
0	0	0	0	0	0	0	0

Table 1: Combustion Efficiency at Different Temperatures and Residence Times (Flare)

Graphically, this would be shown as in Figure 1, below:



As can be seen, all seven temperature lines virtually overlap each other in the case of Methane. Of note, the highest theoretical efficiency is only just over 90%, and this is at 0.25 seconds residence time. A residence time of 0.25 seconds would be nearly impossible to achieve with a flare as it is instantaneously exposed to atmosphere after ignition. And if the flame from the flare did survive for 0.25 seconds the temperature would drop significantly during this time period.

The end result of this low combustion efficiency is unburned hydrocarbons being emitted in the form of black smoke exiting flare stacks as evidenced below.

In contrast, applying the same formula and constants for Methane to the temperatures and residence times that would be experienced in an AWI incinerator, the following combustion efficiency numbers are generated in Table 2:

Combustion Efficiency at Various Temperatures and Residence Times (Longer Residence Times Associated with Incineration)							
Time	Temperature						
t(sec)	650°C	675°C	725°C	750°C	900°C	925°C	975°C
0.3	93.82805388	93.83990715	93.86179391	93.87191816	93.92343514	93.93074451	93.94446952
0.4	97.56090059	97.56714433	97.57866272	97.58398621	97.61102915	97.61485991	97.62204887
0.5	99.03608913	99.03917249	99.04485543	99.04747965	99.06078815	99.06267033	99.06620046
0.6	99.61907081	99.62053256	99.62322426	99.62446613	99.63075360	99.63164138	99.63330551
0.7	99.84946010	99.85013383	99.85137333	99.85194470	99.85483264	99.85523975	99.85600244
0.8	99.94050794	99.94081213	99.94137126	99.94162877	99.94292818	99.94311107	99.94345348
0.9	99.97648926	99.97662445	99.97687273	99.97698698	99.97756250	99.97764337	99.97779470
1	99.99070876	99.99076810	99.99087699	99.99092705	99.99117881	99.99121413	99.99128018
1.1	99.99632818	99.99635397	99.99640125	99.99642296	99.99653199	99.99654727	99.99657581
1.2	99.99854893	99.99856004	99.99858040	99.99858974	99.99863657	99.99864312	99.99865535
1.3	99.99942655	99.99943131	99.99944001	99.99944400	99.99946397	99.99946676	99.99947197
1.4	99.99977338	99.99977540	99.99977910	99.99978080	99.99978926	99.99979044	99.99979265
1.5	99.99991044	99.99991130	99.99991286	99.99991358	99.99991715	99.99991765	99.99991857
1.6	99.99996461	99.99996497	99.99996563	99.99996593	99.99996743	99.99996764	99.99996802
1.7	99.99998601	99.99998616	99.99998644	99.99998657	99.99998719	99.99998728	99.99998744
1.8	99.99999447	99.99999454	99.99999465	99.99999470	99.99999497	99.99999500	99.99999507
1.9	99.99999782	99.99999784	99.99999789	99.99999791	99.99999802	99.99999804	99.99999806
2	99.99999914	99.99999915	99.99999917	99.99999918	99.99999922	99.99999923	99.99999924
2.1	99.99999966	99.99999966	99.99999967	99.99999968	99.99999969	99.99999970	99.99999970

Table 2: Combustion Efficiency at Different Temperatures and Residence Times (Incinerator)

Graphically, this would be shown as in Figure 2, below:

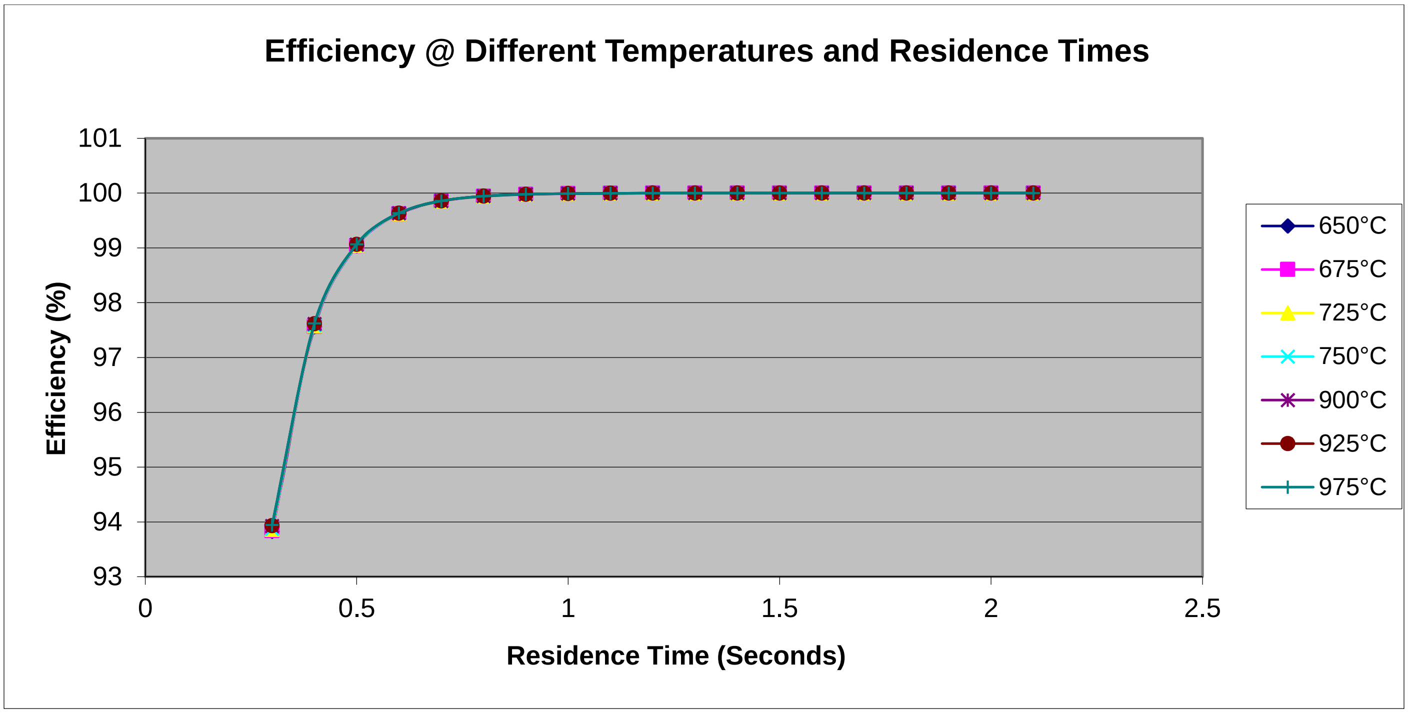
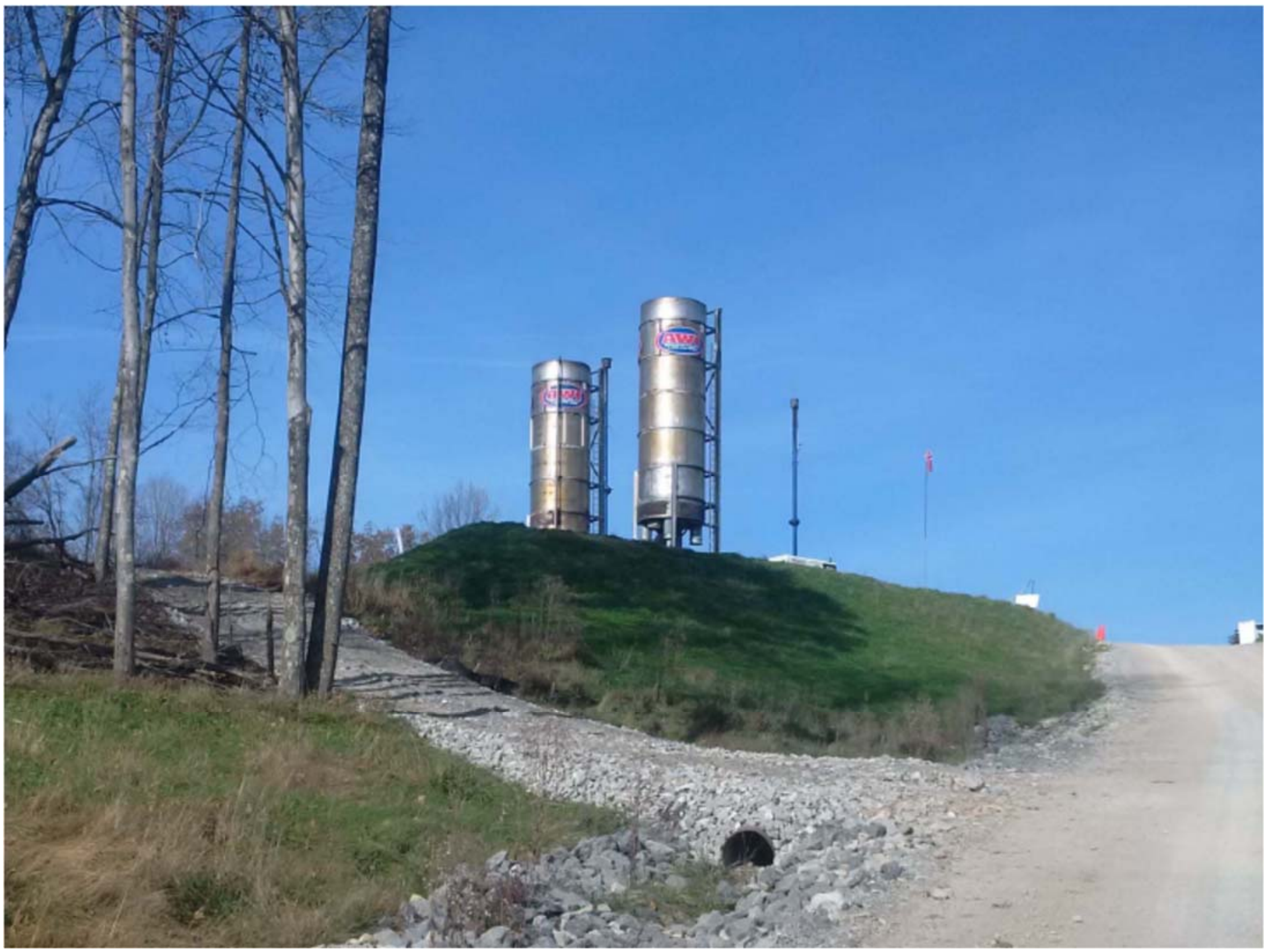


Figure 2: Incinerator Combustion Efficiency at Different Residence Times and Temperatures

As can be seen in the Table and from the Graph, at only 0.3 seconds residence time (below what an AWI unit would operate at) the efficiency is already almost 94%. At the minimum residence time of 0.5 seconds, the efficiency is above 99%. And by one second is already in to the four 9's (99.99%+)

This results in a clean burn with no unburned hydrocarbons (black smoke) released from the AWI units. This is evidenced by the images below of AWI units in operation.



NOTE: Methane Gas was used for the purpose of this illustration of Combustion Efficiency. However, the same basic rules of science apply to all combustible materials: the higher the temperature and the longer the residence time (and the ability to control these) – the higher the Combustion Efficiency will be.

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