Investigation, Validation and Verification of the ZEROS Energy Delivery Process

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ZEROS = Zero-emission Energy Recycling Oxidation System

Executive Summary

The purpose of this report is to provide a summary of the results of an investigation and independent analysis of the energy delivery claims made for the oxidation of a variety of fuels in a pure oxygen atmosphere as described by the ZEROS energy delivery process, which has performed environmental clean up tasks for various private companies over the last 15 years. These cleanup projects were accomplished prior to the development of a corporate policy to commercialize the Thermal Oxidation Technology as a 100% remedial system for various toxic and non toxic wastes. TriEnCon Services has reviewed the historical information, test reports and environmental significance of the various projects completed utilizing this oxidation process.

Due to the differences in technology between “oxidation” and “combustion” of fuels, this analysis effort required multiple steps including research, interviews with chemical industry technical experts, interviews with boiler industry technical experts, and the development of multiple computer programs; in order to fulfill the requirements of process energy delivery validation.

To address the unique nature of the ZEROS process, a simplified explanation of the system provides for a more complete understanding of the differences between a ZEROS powered plant facility and traditional power plant operations.

The ZEROS process consists of a number of commercial “off-the-shelf” component modules. These modules, representing technologies that have been commercially available for many years, in a number of industrial business sectors, are arranged and configured to provide an innovative and highly efficient energy delivery platform for use in combination with conventional steam turbine generators.

The configuration of a ZEROS powered SES (Steam Electric Station) has some general similarities to that of a natural gas fired or coal fired steam power plant:

- A carbon based fuel provides energy to support the generation of steam to drive a traditional Rankine Cycle steam turbine and produce electricity.
- Power Block operation is the same in both facilities.

The principal difference between the ZEROS process and the more common power plant design, lies in the method of production of energy to produce steam. In a typical steam electric station, there is a forced air boiler, usually fired by natural gas, fuel oil, or coal; in which the fuel is burned or combusted to produce heat energy. This heat energy is transferred to water to produce steam. A ZEROS plant can use the same fuels, as well as many other non-traditional fuels, but instead of relying on combustion, the ZEROS plant uses an oxidation process to convert the fuel source to heat energy. As in the conventional power plant, this heat energy is transferred to water to produce steam.

Basic System Description

It is important to provide a general description of the ZEROS System so that comparisons made with traditional power plants and the analysis of the energy released from oxidation as contrasted to combustion have relevant points of reference. Simply described, the ZEROS power plant contains the following basic component blocks:

- Fuel Handling
- Rotary Kiln (Primary Combustion Chamber) and Secondary Combustion Chamber
- Slag, Fly-ash Recovery, and Waste Gas Recovery
- CO_2 Recovery & Distilled Water Delivery
- High Temperature Heat Exchanger, Condensate and Feedwater Systems
- Steam Turbine Generator
- Circulating Water and Cooling Tower

Definition of Oxidation

"Oxidation is the process of adding an electro-positive oxygen atom to a compound". In the ZEROS process, the oxidation of fuel to produce energy can be summarized as follows: fuel and oxygen are brought together in the Primary Combustion Chamber at high temperature and as a result, the molecular breakdown of the fuel compounds into principally Hydrogen and Carbon Monoxide occurs. This initial oxidation releases the traditional heating value of the fuel (usually described in Btu/Lbm). These resulting hydrogen and carbon monoxide by-products of the primary oxidation process are then re-oxidized in the Secondary Combustion Chamber with the addition of quantities of pure oxygen to form water (high temperature steam) and carbon dioxide. This re-oxidation process of hydrogen and carbon monoxide is an exothermic reaction (releases the heat of combustion (Btu/Lbm) for both the formation of water from hydrogen and the formation of carbon dioxide from carbon monoxide). The specific amount of additional energy released in the secondary oxidation process is a function of the molar ratio of hydrogen to carbon monoxide, which is directly associated with the chemical analyses of the fuel sources or fuel blends. As a result of the two-step energy release found in the ZEROS oxidation process, the total energy released per pound of fuel consumed is greater than the energy released by more traditional combustion processes. Modeling of various fuel sources reveals that the typical values for this additional energy released can range anywhere from 35% to 80% of the nominal heating value of the fuel and is very fuel source specific. As an example, for natural gas as a fuel the additional energy released is approximately 35%, whereas for car tires, this value approaches closer to the 80% value.

System Characteristics

Several physical features of a ZEROS facility are also unique due to the component modules configuration and the nature of the Oxidation process.

- No exhaust stack or atmospheric emissions are present for the conversion of the fuel to heat energy
- Instead of requiring a forced-air combustion system, ZEROS is an oxygen-blown oxidation system
- The ZEROS process has a closed system configuration

As a result of the physical plant configuration previously described, there are several significant cycle efficiency benefits gained by this ZEROS plant and energy delivery process:

- The lack of an exhaust stack reduces process energy (heat) loss to the atmosphere. The high temperature steam and carbon dioxide are able to impart more of the total energy available by heat transfer process to the secondary steam system. This increase in heat transfer is approximately 13% to 15%. This is the value typically associated with boiler stack losses for traditional power plant boilers.
- The oxygen blown arrangement of the system reduces heat energy losses due to a reduction in process mass flow of approximately 80%. The oxygen content present in air is approximately 20% with the remainder comprised principally of nitrogen. In a conventional boiler, combustion is normally accomplished by the control of excess oxygen concentrations at about 2%, which correlates to an excess air flow of about 10%. The pure oxygen process used by ZEROS in fuel oxidation is typically operated at 5% to 6% excess oxygen. As a result of the use of pure oxygen, slightly more than an 80% reduction in the mass flow required for fuel to energy conversion is achieved.

- The reduction in mass flow reduces the loss of energy necessary to bring the much larger air flow / mass flow in a traditional steam boiler up to temperature, resulting in a more efficient use of the energy released from the fuel in the ZEROS process.
- An additional benefit occurs in the High Temperature Heat Exchanger (HRSG). Instead of relying on the burner flame radiant heat transfer (furnace area) and the convection heat transfer capability of hot air moving across boiler tube surfaces, an increased heat transfer capability (convection and conduction) occurs due to the characteristics of the hot steam and CO_2 exhausting from the Secondary Combustion Chamber making contact with the boiler tubing. This increase in heat transfer capability will tend to improve the relative efficiency of the HRSG by several percentage points.

The ZEROS system is described as "closed" in that all of the fuel and oxygen energy released, as well as the fuel oxidation by-products are captured for use within the rankine cycle, or as viable by-products with revenue streams, or as consumables for the oxidation process. The traditional power plant, whether natural gas, oil fired, or coal fired must generally rely on a singular source of revenue i.e., the production of electricity. The noticeable lack of airborne emissions and liquids discharges from the ZEROS process provides for a much more environmentally benign plant facility. The increase in fuel energy released and energy conversion efficiency, and the presence of a number of revenue producing oxidation process by-products streams, including the complete sequestration of all CO_2 produced, results in significant improvements in the financial feasibility of the ZEROS facility.

Analysis of the ZEROS Energy Delivery Process

Following a thorough review of the publicly available information on the ZEROS process and the associated plant configuration and technologies employed, the following investigative and analytical steps were taken to validate the energy delivery capabilities of the ZEROS process:

- Visits were made to oil and gas refineries in Texas to meet with various senior chemical engineers for discussions on both the chemistry and the technology associated with oxidation. Results of these meetings were beneficial in that the chemical engineers interviewed had first hand knowledge of oxidation processes and were able to validate the oxidation concepts and methodologies. Additionally, during these meetings, the ZEROS process energy release claims were substantiated by rough calculation using fuel oil and natural gas as principal fuel sources.

- Visits were also made to a North Texas Steam Electric Station to obtain steam turbine performance test data for steam generating units of approximately 50 Mw in size. Three units' performance test data were analyzed (47 Mw, 58 Mw and 65 Mw) for required steam mass flow, temperature and pressure; feed-water flow and energy transfer requirements, turbine exhaust conditions, condenser performance, boiler performance, heat loss and heat transfer characteristics, and cooling tower performance. This unit specific test data was combined with other unit test data available from larger steam electric units and research information collected from reference sources, and comprised the basis for the initial characterization and general specifications of energy delivery requirements from the ZEROS process. Use of these data sources enabled TriEnCon to calibrate the computer models that had to be developed to support the validation of the ZEROS process energy delivery and heat exchanger heat transfer requirements.

- Contact and discussions were undertaken with technical representatives of the manufacturers of heat recovery steam generators (hrsg) to determine heat transfer capabilities and compatibility with the projected ZEROS Secondary Combustion Chamber outlet mass flow and temperature conditions. Several of the manufacturers made preliminary HRSG configuration modeling software runs to validate the heat transfer capabilities and the required metallurgy for sizing a HRSG. TriEnCon was able to verify from these discussions and manufacturer modeling, the capability of various boiler manufacturers to deliver a HRSG with the desired energy input and energy delivery characteristics.

- A computer model was developed by TriEnCon to analyze the energy requirements (steam mass flow, pressure and temperature) of the different steam turbine generators (using a combination of the steam generator performance test data for more than 15 different generating units). This computer model was calibrated with the available test data. These modeling runs provided a high degree of precision for the energy output requirements that must be provided by the High Temperature Heat Exchanger (HRSG) in order to support a 50 Mw (gross output) or other desired size electrical capability. Computer model results were able to be calibrated with unit specific test data within an accuracy level of (+/-) 2%. This degree of modeling accuracy is consistent with the level of accuracy provided by ASME performance test data.

- Use of this computer model allowed for the analysis of the projected thermodynamic and heat transfer characteristics and operating conditions of the High Temperature Heat Exchanger or (HRSG), based on the projected steam and carbon dioxide gas conditions and mass flow at the outlet of the Secondary Combustion Chamber. Heat energy transfer from the outlet of the Secondary Combustion Chamber to the outlet of the

High Temperature Heat Exchanger (energy released across the Heat Exchanger) was calculated using combustion engineering standards for boilers/heat exchangers as referenced in "Steam" by Babcock and Wilcox, and from the actual test data from a variety of boiler configurations and manufacturers. The projected energy transfer between the oxidation process energy released and the secondary steam energy provided to the steam turbine fell within the calculated values and projections for energy to be delivered from the heat exchanger. Modeled results indicated that the ZEROS process should indeed be capable of delivering adequate energy to drive a 50 Mw steam turbine to full capability (50 Mw gross).

- A second computer model was developed by TriEnCon to analyze the performance of the ZEROS process and to determine the energy delivered from various fuel types and blends using the ZEROS oxidation methodology. This model takes into consideration and utilizes the following:
  - The chemical analyzes of projected fuel sources and/or blends of fuels:
    - Moisture %
    - Ash %
    - Carbon %
    - Hydrogen %
    - Oxygen %
    - Nitrogen %
    - Chlorine %
    - Sulfur %
  - Operating conditions in the Rotary Kiln (Primary Combustion Chamber)
    - Operating Temperature
    - Fuel Flow
    - Excess Oxygen

- Rotary Kiln Combustion By-Products (Oxidation By-Products) and Ash Balance to determine total Energy Available from the Rotary Kiln and the calculated mass flow out of the Rotary Kiln.
- Secondary Combustion Chamber inlet and operating conditions:
  - Inlet Temperature
  - Mass Flow
  - Excess Oxygen
  - Ash Balance
- Determination of Secondary Combustion Chamber outlet conditions:
  - Mass Flow (Lbm/hr)
  - Outlet Temperature
  - Total Available Secondary Combustion Chamber Energy (MMBtu/Hr) delivered to the High Temperature Heat Exchanger

- The second computer model was run utilizing a variety of fuel types and blends for comparison with calculations provided from ZEROS Energy Systems International. Included among the various fuels analyzed were:
  - Natural Gas
  - Car Tires
  - Polystyrene, Polyethylene, Polypropylene
  - Wood Pulp
  - Cow Manure / Sewer Sludge

- The energy release as calculated for the various fuels by the second computer model were found to be universally within 2-3% of those provided by the ZEROS Inc. calculations. In each case the TriEnCon model estimated a slightly higher level of energy delivered for each fuel type or each fuel blend. The magnitude of the difference in energy delivered was attributed to modeling round off error and interpolation error in determining energy levels (enthalpies) at various points in the oxidation process.

- In addition to the TriEnCon efforts at validating the energy released for the fuels listed, a third party chemical engineer (working independently and without the knowledge of TriEnCon) utilizing petrochemical refinery software was able to come to the same conclusions on energy release for several of the same fuel sources with a similar level of accuracy.

Conclusions

TriEnCon Services conducted a combination of detailed research and investigative efforts that culminated in the development of two complex computer models for the validation and verification of the energy delivery capabilities of the ZEROS process. Numerous modeling runs were undertaken for various plant configurations and sizes as well as for various fuel sources and characteristics. TriEnCon was unable to find any fault in the ZEROS process energy delivery claims. All evidence and findings point to the successful capability of the ZEROS process to deliver energy at the proscribed rates for any given fuel combinations and blends, as well as the ability of the process to deliver adequate levels of energy into a high temperature heat exchanger to support the operation of a 50 Mw steam turbine generator (gross Mw). Additionally, our analysis points towards the capability of the ZEROS process to conservatively deliver an equivalent heat-rate (energy efficiency level) of approximately 6,200 Btu/Lbm for the standard rankine cycle. This equivalent heat-rate is better than the current state-of-the-art combined cycle combustion turbines.

Thomas E. Boyd, P.E.
TriEnCon Services, Inc.

Curriculum Vitae

Thomas E. Boyd, P.E.

Co-founder of TriEnCon Services Inc. with more than 30 years of Power Generation, System Operations, Project Management, Due Diligence, Electric Utility and Energy Trading support experience. TriEnCon Services is an energy services firm providing a combination of consultation services to large utility customers, project management and professional staffing support to both the nuclear industry and conventional power projects. Additionally, TriEnCon has developed and markets a number of innovative utility industry processes, real-time information systems, and operational solutions.

System Operations

Manager of Availability Support and Fuel Coordination for TXU Electric. Coordinated Fuel Management, Overhaul and Outage Scheduling. He managed the Generation, TUMCO, TUFCO, Fuel Acquisition, and Western Coal coordination interfaces with Power Supply (System) Operations. He developed and implemented the concepts of the Generating System Information System, Unit Cycling Costs, Lignite Fuel Management, the first TXU Off-System sales of electricity and initiated the evaluation and selection of alternative System Scheduling/Unit Commitment Tools.

Data Systems Management

Has extensive development experience in the conception, creation, and development of business and operational data systems. Additionally, has a working knowledge in OSI PI, PI Data Systems and data integration with PI Data Systems, Oracle, and SQL Server data warehouses through web interfaces.

Energy Trading

Director of Market Information & Competitive Intelligence at TXU Energy Trading managed an innovative team for the development and implementation of competitive intelligence, market information and business information automation systems: data mining and data management, trade desk software applications, real-time data systems monitoring system operating parameters, and web-based (OIS) operations information & communication systems.

Engineering Project Management

More than 15 years of engineering project management experience. As Manager of Generation Services (Projects) for TXU Electric, was accountable for the prioritization, development, and implementation of operational systems, databases, and models for TXU Production transition to a deregulated market environment. Major capital projects included NOx Compliance Management System, OSI-PI system implementation, and Oracle Database (hardware and database structure) development projects totaling in excess of $30 million.

Outage Management

Over 9 years experience in Generating Facility Overhaul and Outage Management. As Manager of Projects for TXU Electric, with18-20 Project Managers to provide Project Management support for Engineering Construction, Maintenance and Capital Improvement projects for the Generating Division's 60+ units. Managed Maintenance and Capital projects in excess of $30 Million annually and coordinated the contracting for and contract development of major Third Party Service Contracts.

Power Plant Operations/Due Diligence

Has more than 21 years of plant operations experience: including the due diligence evaluation of multiple plant facilities, over 5 years operating experience in Naval Nuclear Propulsions Systems and A1W, D2G Nuclear Reactor Systems. Commercial operations experience includes more than 16 years of combustion turbine (GE Frame 7EA) and large coal/gas steam generating facility operations.

Education & Qualifications

A 1975 graduate of the U.S. Naval Academy, a Captain in the U.S. Naval Reserve (Ret.) and a Registered Professional Engineer in Texas.