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Comment Received From: Brian Kolodji, PE
Submitted On: 9/24/2020
Docket Number: 19-ERDD-01

Fw 19-ERDD-01 and Advanced Combustion â€“ Request for Information

Additional submitted attachment is included below.

From: Brian Kolodji
To: Gchen@enerflex.com
Cc: Marc Straub; Energy - Docket Optical System
Subject: Fw: 19-ERDD-01 and "Advanced Combustion – Request for Information"
Date: Wednesday, September 23, 2020 10:30:18 PM
Attachments: occ2Final00037OxEnrich Article 2011.pdf

CAUTION: This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Dr. Chen,

You have published a very interesting article titled "Calculate the Power of Cryogenic Air Separation Units" published in the June 2020 issue of the Chemical Engineering Progress Magazine. This email is specifically in regards to oxygen production and power consumption using Cryogenic Air Separation Units (ASUs). I was hoping you might comment on the above calculation below and provide further details for the "Request for information" by the California Energy Commission, specifically on power requirements and capital costs for cryogenic separation units (see the requested info below this email). The request is very short notice, with the information due by 5PM California time tomorrow, but I figured if anybody could give a quick answer, it would be you.

In your article, you state that an ASU can be designed to produce solely 95% pure oxygen from air (at 20.96% oxygen) and the power consumption can be calculated by summing terms for separation, compression, and liquefaction. The feed air must be pressurized in an ideal design (meaning assuming no piping/ equipment pressure losses and temperature difference in the vaporizer is zero and the production of only gaseous oxygen) to an operating pressure of 0.3658 MegaPaschalls (MPa) minimum from an ambient pressure at 0.1013 MPa, yielding an actual separation power of 55.8 Kilowatts (KW) to produce 209.3 Normal Meter Cubed of Oxygen gas per hour (NM3/Hr), or 3606 Metric Tons per Day (MT/D). This is equivalent to 0.0153 KW to produce 1 MT/D, or 0.381 KW to produce 25 MT/D, or 1.53 KW to produce 100 MT/D. These power consumption values specifically exclude power term for liquefaction of the oxygen, as this I am proposing minimum concept costs.

As you may not know, I am also a member of AIChE and a chemical engineer. Also, I am California business owner of Kolodji Corp and Black Swan, LLC. I have patented and patent pending devices, methods, and processes, including membrane designs and processes for oxygen enrichment and oxy-combustion. I have designed oxy-combustion systems for several companies, including Shell Oil and Lyondell Corp, specifically to increase refinery sulfur plant capacity by 300% using high grade (95%+ pure) cryogenically produced oxygen. As for membranes, I have worked for the largest gas separation membrane supplier (UOP/Honeywell) and then for the largest membrane user in off-shore oil and gas production (MODEC.) My Black Swan, LLC oxygen producing technology from air has been prototyped with Generon, a Dow Chemical Legacy Company with membrane manufacturing in California, and piloted with membranes fabricated and supplied by Generon. The fifth Black Swan, LLC technology pilot plant is planned for later this year, with a funded demonstration plant, and with plans for 2021 demonstration/ industrial scale plants at a refinery cogen unit (5 MW), two biogas power plants (up to 2 MW), and three other industrial scale plant boiler operations (up to 50MMBTU/Hr.) The membranes are used for separating oxygen (and CO_2) from air, without pressurizing the feed air, that saves up 50% in natural gas firing rates, reduces GHG emissions by as much, with only 15% of the savings used on parasitic, but green, energy use. An article on oxy-combustion article is attached.

Thought you at Enerflex Energy Systems (your phone number 832-230-9936?) might want to weigh in on this recently received email (again, see below) regarding the request for information (again, due tomorrow, Thursday, September 24, 2020 by 5PM California Time) from the California Energy Commission on oxygen production, power consumption, and capital costs, as well as other operating costs using cryogenic air separation processes (specifically mentioned) such as the cryogenic double column ASU for solely oxygen production as described in your article, and Oxy-combustion technology as well.

Please let me know.

Regards,

Brian Kolodji, PE

Kolodji Corp/Black Swan, LLC

Energy Carbon Management
Cell: (713) 907-8742

5612 Segovia Way, Bakersfield, CA 93306

2019/2020 Chair Carbon Mgt and Sustainability,

AIChE National Meetings

"...Peace be with you..."

----- Forwarded Message -----

From: California Energy Commission <listenergia@listserver.energy.ca.gov>
Sent: Friday, September 4, 2020 4:26 PM
To: NATURALGAS@LISTSERVER.ENERGY.CA.GOV
Subject: [EXTERNAL] NATURALGAS-LIST: Advanced Combustion Technologies - Request for Information

*** EXTERNAL EMAIL - Be cautious of attachments, web links, and requests for information ***

California Energy Commission Newsletter Logo

California Energy Commission Newsletter Logo

September 04, 2020

The California Energy Commission (CEC) is gathering information to inform a solicitation for a future solicitation on oxygen-enriched combustion and would appreciate your responses to the following:

1. **The following will help us target our specific research:**

   a. What are major barriers (technical, economical, and other) for wide adoption of oxygen-enriched combustion?
   b. What are examples of research that could eliminate barriers to wide adoption of oxygen-enriched combustion?
   c. What are examples of current or past projects involving oxygen-enriched combustion? What are important lessons learned from these projects?
   d. What California industries could benefit most from oxygen-enriched combustion?
   e. What are technical challenges that could result from higher oxygen content and higher combustion temperature (e.g., increased NOx emissions; accelerated degradation of materials in burners, furnaces, kilns)?
   f. Provide examples of existing projects using centralized oxygen generation, distribution via pipeline networks or other approaches that could benefit from R&D.

2. **The following will help us establish performance metrics and technology status in California:**

   a. Besides cryogenic separation, pressure/temperature swing absorption, ion transport membranes, are there any other promising technologies that should be considered?
   b. For the technologies listed in item 2a:

      i. What is the estimated energy requirement to produce oxygen at the following capacities: 1 metric ton of oxygen per day, 25 metric tons per day, 100 metric tons per day
      ii. What is the estimated capital and operational costs for 1 metric ton per day of oxygen production capacity?

   c. Identify California research teams working on oxygen-enriched combustion.
   d. Identify California companies who develop and sell equipment for oxygen production and oxygen-enriched combustion.

Written comments must be submitted to the Docket Unit by **5:00 p.m. September 24, 2020**.

Written comments, attachments, and associated contact information (e.g., address, phone number, email address) become part of the viewable public record. This information may also become available via any internet search engine.

The CEC encourages use of its electronic commenting system. Please submit your comments to the Docket Unit at https://efiling.energy.ca.gov/Ecomment/Ecomment.aspx?docketnumber=19-ERDD-01. Select or enter a proceeding to be taken to the "Add Comment" page. Enter your contact information and a comment title describing the subject of your comment(s). Comments may be included in the "Comment Text" box or attached in a downloadable, searchable Microsoft® Word (.doc, .docx) or Adobe® Acrobat® (.pdf) file. Maximum file size is 10 MB.

Written comments may also be submitted by email. Include docket number 19-ERDD-01 and "**Advanced Combustion – Request for Information**" in the subject line and send todocket@energy.ca.gov.

For more information:
https://www.energy.ca.gov/publications/displayOneReport_cms.php?pubNum=CEC-500-2019-035
(If link above doesn't work, please copy entire link into your web browser's URL)

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2nd Oxyfuel Combustion Conference

Reduction of Fuel Consumption and Emissions of a Gas Turbine by Using of Oxygen-Enriched Combustion

Cristiano Frandalozo Maidana, Adriano Carotenuto, Paulo Smith Schneider

Federal University of Rio Grande do Sul, Porto Alegre, Brazil

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Keywords: Oxygen-Enhanced Combustion, fuel consumption, emission reduction, gas turbine design

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1. Abstract

The majority of combustion processes uses air as oxidant, roughly taken as 21% O_2 and 79% N_2, by volume. In many cases, these processes can be enhanced by using an oxidant that contains a proportion of O_2 a little bigger than in regular air. This is known as oxygen-enhanced combustion or OEC, and can bring important benefits like higher thermal efficiencies, lower exhaust gas volumes, higher heat transfer efficiency, reduction fuel consumption, reduced retrofit costs and substantially pollutant emissions reduction. Within this scenario, this paper aims to investigate the behavior of a gas turbine power plant fed by a oxidant stream ranging from 21 to 30% oxygen concentration, at steady state operation and with a net power output of 30MW. Simulations show that the retrofit with OEC reduces both fuel consumption on about 25% and flue gas formation of up to 30%. However, it was necessary a supply of 0.20 kmol/s of pure oxygen to sustain the process.

2. Literature Review

Oxygen enhanced combustion (OEC) technology is one of the useful energy-saving technologies for combustion systems. Although nitrogen in the air is an inert gas it actually reacts at high temperatures and also carries away a significant part of the energy of the reaction, lowering the fuel availability. In contrast, OEC combustion can overcome this disadvantage due to the lower nitrogen concentration involved.

According to Bisio et al., 2002, the barrier to couple oxygen to power cycles is the high cost of oxygen production on cryogenic plants, but the use of membranes technology to obtain an enriched stream with 30-45% oxygen may offset the costs of oxygen implementation with the fuel saving obtained.

Wu et al., 2010, studied the influence of oxygen concentration ranging from 21 to 30% in natural gas combustion (in the heating and furnace-temperature fixing tests). They noticed a gain on fuel consumption of 26.1% operating at 30% O_2 , compared to regular atmospheric concentrations (21% O_2), with furnace temperature of 1220°C.

3. Method

In order to access the behavior of a gas turbine for power generation running on EOC with oxygen concentration ranging from atmospheric contents to up to 30%, a thermodynamic model was proposed, as depicted at Figure 1. The gas turbine cycle presented is assembled by a compressor, an expansion turbine, and a combustion system. This last one is composed by a combustion chamber and auxiliary devices, as an air splitter, a gas mixer, and an oxygen injector.

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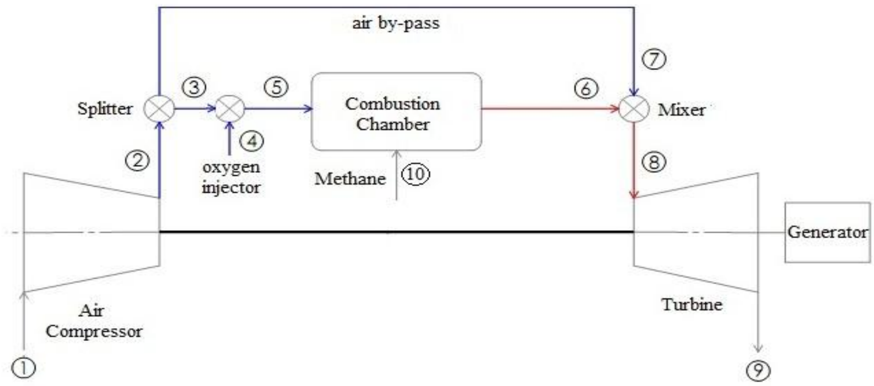

Figure 1: Gas turbine schematics for Oxygen-Enriched Combustion (OEC)

Simulations were performed considering the adiabatic combustion of natural gas (methane) at a temperature of 2000K, with a prescribed flue gas temperature of 1100ºC at the turbine inlet. Atmospheric air was taken as 79% N_2 and 21% O_2. The most relevant quantities calculated by the simulation model are the reactant molar flow rates (fuel and oxygen), the stoichiometric ratio in the chamber combustion and molar flow rate of flue gas.

Flue gases stream was taken as: N_2, O_2, CO_2, H_2O, OH, H_2, NO, NO_2, CO, O, H, N. Their molar concentrations were validated by the CEA-NASA software (Chemical Equilibrium with Applications), developed by Gordon et al. in the Glenn Research Center of NASA.

The complete set of equations was solved with the Engineering Equation Solver (EES), an algebraic non-linear solver with an integrated library of thermodynamic property of species

The parameters of the simulation are listed in Tab. 1 for all the proposed cases, segregated by equipment. The net power output for all the simulations was 30 MW.

Table 1. Simulation parameters

Air Compressor T_1 = 298.15 K (25 °C), p_1 = 1,013 bars (1 atm) Air molar analysis: 21% O_2 and 79% N_2 Pressure ratio: p_2/p_1 =18, η_c = 0.65	Splitter Air molar analysis: 21% O_2 and 79% N_2 in streams 3 and 7, p_2 = 18.23 bars
Oxygen injector 100% O_2 in stream 4, $T_4 = T_1$	Combustion Chamber p_6 = 10.13 bars, T_{10} = 298.15 K, T_6 = 2000 K
Mixer T_8 = 1373.15 K (1100 °C)	Turbine η_t = 0.86

The variables of the system are presented in Table 2:

Table 2. Simulation variables

Air Compressor $T_2, T_{2,s}, \bar{h}_2, \bar{h}_{2,s}, \dot{n}_1, \dot{W}_c$	Splitter $\dot{n}_3, \dot{n}_7$
Oxygen injector $\dot{n}_4, \dot{n}_5$	Combustion Chamber $\varphi, \dot{n}_6, \dot{n}_{10}$
Mixer $\dot{n}_8, y$	Turbine $T_9, T_{9,s}, \bar{h}_9, \bar{h}_{9,s}, \dot{W}_t, \dot{n}_9$

4. Results and Discussions

The Fig. 2 shows the reduction of fuel (methane) with increasing oxygen concentration of the oxidant input stream of combustion chamber. This enhanced oxygen combustion leads to a net reduction of nitrogen flow rate:

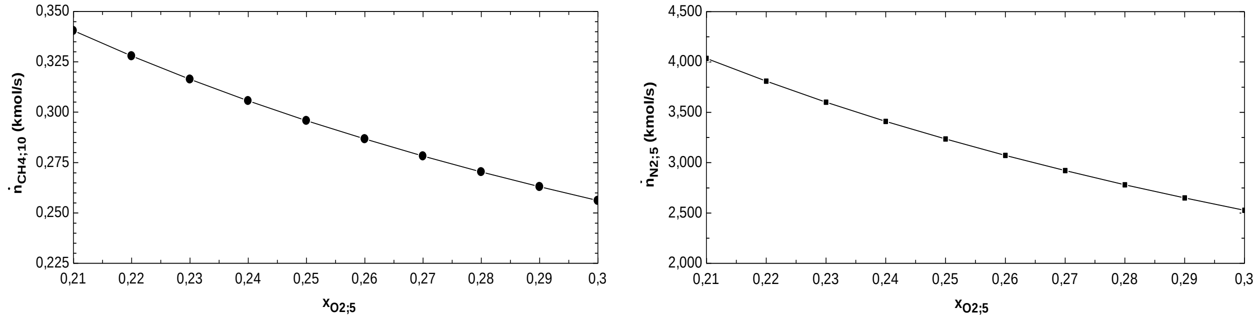

Figure 2. Fuel consumption (left) and nitrogen molar flow rate in stream 5 (right) as a function of molar fraction of oxygen in the oxidizer, for an adiabatic combustion of methane and T_6 = 2000K

As a result of the reduction of the air flow rate intake at point 3 (and thus, the nitrogen concentration), an addition of pure oxygen flow rate is needed in order to keep the combustion process at stoichiometric condition. In contrast, a reduction of gas flue gas is achieved. These characteristics are show in Figure. 3:

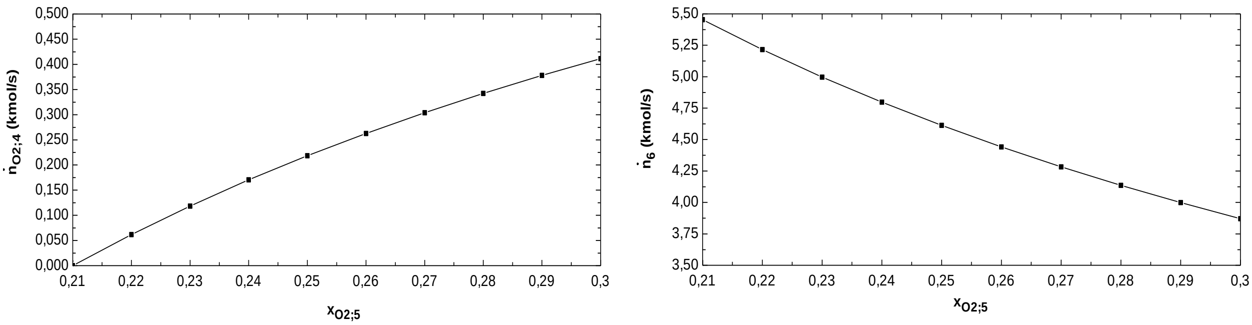

Figure 3. Molar flow rate of oxygen delivered by the injector (left) and molar flow rate of exhaust gas leaving the combustion chamber (right) vs molar fraction of oxygen at the entrance of the combustion chamber for an adiabatic combustion of methane and T_6 = 2000K

Figure 4 displays the reduction in power cycle emissions for two major pollutants (CO_2 and NO) with respect to the oxygen concentration in the oxidizer stream. Results have a maximum deviation of 3% compared to those obtained with the software CEA-NASA:

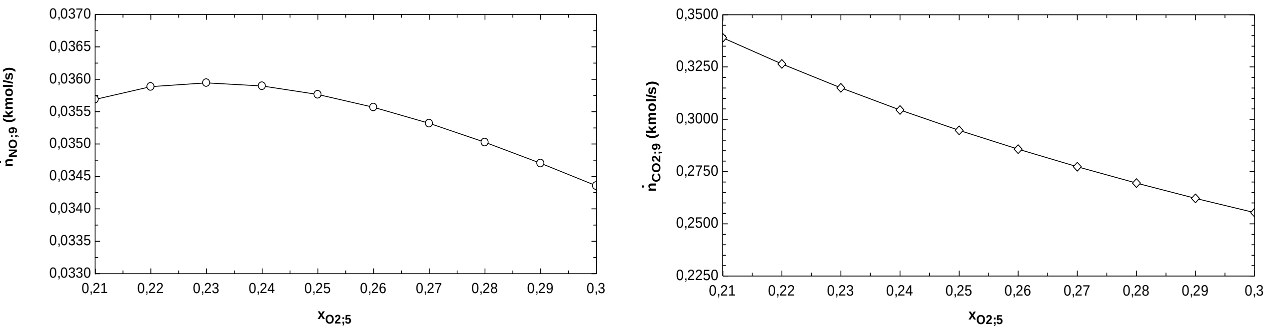

Figure 4. Reduction in the molar flow rate of NO (left) CO_2 (right) emitted by the gas turbine vs the molar fraction of oxygen in the oxidizer for an adiabatic combustion of methane and T_6 = 2000K

5. Conclusion

In this work, a gas turbine cycle was modeled and simulated with a special attention to the description of the combustion process within the combustion chamber and its auxiliary devices, needed to represent a more realistic enhanced oxygen combustion (OEC) process. This paper aims to be a proof of concept of the OEC applied to gas turbines. As a preliminary approach, the temperature at the combustion chamber was left free to reach higher levels, compared to combustion with air. Main emission products were limited to N_2, O_2, CO_2, H_2O, OH, H_2, NO, NO_2, CO, O, H, N, modeled by chemical equilibrium

Results showed a reduction of up to 24.8% on fuel consumption on OEC compared to the standard case, i.e., oxidizer at atmospheric composition. Moreover, it was also possible to achieve a significant reduction in the formation of major pollutants. Emissions displayed a maximum decrease of 3.75% for NO, 24.7% for CO_2 and 47.9% for CO. However, there was a need for pure oxygen supply (stream 4) that achieved $6.67\text{x}10^{-6}$ kmol per kJ of electrical output when operating at 30% concentration. To overcome this penalty, this oxygen flow could be supplied by a low-cost technologies, such as membranes, PSA (pressure swing adsorption), TSA (thermal swing adsorption), among others.

6. Acknowledgements

The authors thank the Brazilian Research Council CNPq due to the financial support by means of a Masters Degree scholarship, a Doctor Degree scholarship and a research grant, respectively, as well as to the CNPq Mineral Coal Research Net and the international cooperation CAPES/PROBAL/Process/ nº348-10.

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