Development of an Oxygen Concentrator (Generator) for use in a waste oil burner (gasification process)

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***Abstract*—**Environmental pollution by industrial combustion and heating processes is a major concern and problem faced by humanity. For future generations, there is an urgent need to conserve our environment to curb carbon dioxide emissions and reduce other harmful pollutants generated during combustion of fossil fuels. This calls for proactive approaches in dealing with combustion of fossil fuels and pollution control as opposed to reactive approaches.

A lot of research is ongoing to avert pollution due to combustion of fossil fuels. A major breakthrough has been combustion in a stream of pure oxygen as opposed to use of air in combustion. One of the key benefits in the elimination of nitrogen from air in combustion is reduction of NOx level produced, and higher flame temperatures can be attained thus extracting as much energy content from the fuel. Existing oxygen generation systems have weaknesses and challenges in that it is expensive and mostly not available on site.

This research involves development of an onsite oxygen generator for use in oxy-fuel and gasification process with capability to produce oxygen with purity of 95 percent. The method to use is adsorption sieve technology to generate oxygen from air at ambient temperature.

It is expected that the designed oxygen generator will be tested to see the effect of its geometry, and test the influence of flow parameters on its performance. This will go a long way in environmental conservation and ensure that fossil fuels re a clean source of fuel for use in power generation and industry.

Keywords - Combustion, oxygen generator, pollution.

I. INTRODUCTION

The use of fossil fuels for energy production and heating is very important for economic growth and for industrial processes and operations. Unfortunately, the use of fossil fuels has contributed a lot in terms of air and environmental pollution and degradation. The combustion of the fuels occurs in presence of air or a stream of air. The air is composed of many elements but oxygen is the only supporter of combustion.

Industrial combustion is key to industrial processes and power generation by converting the energy in fossil fuels to a usable form for driving engines, providing heat requirements and power generation. However, industrial and economic expansion has come at a cost and it is the biggest contributor to air pollution globally. The by-products of combustion in air are the NOx, SOx, carbon monoxide and CO_2, which are all pollutants. Pollution has been blamed on environmental degradation, global warming, and chronic respiratory health complications afflicting populations especially in industrially populated areas and its environs.

The best bet on the control of pollutants is pre-combustion control, by carrying out combustion in a stream of air highly enriched in O_2 with N_2 removed and eventual capture of CO_2 in a process known as carbon capture and sequestration (CCS) [17][20][28][36][37]. The capture rate for CO_2 is 100% with purity of 95% when combustion takes place in a stream of 95% pure O_2 [21] [28].

II. LITERATURE REVIEW

The three main methods that have been used for pollution control in power plants are pre-combustion control, post combustion control and oxy-fuel combustion.

Oxy-fuel combustion is proving to be the best bet so far. This technology entail carrying out combustion in a stream of oxygen as opposed to air. The oxygen can be gotten in a variety of ways from chemical reaction generation and separation of air into its primary components. Industrially air separation offers better economics and in this regard they are further classified into two methods, cryogenic air separation and non-cryogenic air separation.

a) CRYOGENIC AIR SEPARATION

Cryogenic air separation technology utilizes cooling and liquification of air, then selectively distilling the components at the various boiling points. The process is good when purity greater than 99.99% are desired, volumes larger than 1000 tons per day are required. Due to the fact that cooling is an essential step, the process is energy intensive and very expensive to set up [20] [21]. For a typical power plant the total set-up cost for a cryogenic ASU (Air Separation Unit) is around 15% of the total power plant cost [8][11][20], with its

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energy requirements to operate it being in the range of 10% of the total power produced [8][20]. The energy consumption is substantial and for a modern cryogenic installation, it amounts to about 200kWH/t of oxygen [37], exceeding thermodynamic minimum (53.1kWh/t of oxygen) by almost 4 times. The space requirements are quite sizable [20]. An ASU capacity of 2000 tons per day requires and area of 10,000M^2 [21]. However, modern cryogenic air separation units (ASU) use expansion turbines for cooling; the output of the expander helps drive the compressor and efficiency is improved [8] [9] [30] [31].

Pawel Gladyz and Andrzej Ziebik[17] did a system approach to exergy analysis of a conventional coal fired power plant and oxy-fuel power plant with CO_2 transport and storage. They looked at the input-output model evaluating direct energy and material consumption, local exergy losses, cumulative exergy consumption and losses, and cumulative exergy efficiency. They observed that in as much as cryogenic air separation is efficient in CO_2 capture, transport and storage, the energy and exergy analysis points to a greater need for improvement in the processes for better utility, energy reduction and improved efficiency.

Dowling et al [30], in there research on an advanced equation based flow sheet to optimize a framework of cryogenic air separation design systems for oxy-combustion in power generation, established that cryogenic air separation is an efficient system and good for CO_2 capture system, in a fossil fuel power plant, but they did identify that it is a challenge in design because of the very low temperatures and refrigeration cycles involved thus requiring a very tight integration.

b) NON-CRYOGENIC AIR SEPARATION

There are three main technologies used namely, membrane technology, chemical process and molecular sieving (adsorption) technology.

1) Membrane Technology

This technology involves passing air over a membrane filter. The membranes can be nano-porous or polymer, and the gas molecules penetrate according to their size or difusivity. The filter allows fast gases to pass through and the slow gases are retained and they are called retented gases. Oxygen is considered a fast gas, and nitrogen and argon are considered slow gases.

Varying levels of purity, upto 50 percent, can be achieved by varying the time that the gas spends undergoing filtration [13]. Its by-product capability is very low since the by-products still has other contaminants. Membrane technology has quick start-up times and operates at near ambient conditions, with low safety concerns. Capital costs with membrane systems increase linearly with output volume desired. Currently, membrane technologies can satisfy needs of up to 20 tons of oxygen/day. Its running and operation costs are low and

is favored in situations where required oxygen purity is low and the budget is limited. In the recent past there have been technological breakthrough in the membrane technology.

The ion transport membrane (ITM) has been developed by Air Products and Chemicals, in conjunction with the United States Department of Energy and Ceramatec. Reports have shown that this technology can produce greater than 99 percent purity O2 at much lower costs than cryogenic separation[8][11][13]. This technology is still under research and its efficiencies are very low [37].

2) Chemical Process

A number of materials have the ability to absorb oxygen at one set of pressure and temperature conditions, and release the oxygen at a different set of conditions. Air Products and Chemicals have investigated into this process and found that molten salt is a good candidate [8] [13].

Air Products and Chemicals operated a small-scale pilot unit that verified 99.9 percent oxygen purity at expected salt loading [13], however, corrosion of the salt/oxygen two-phase areas of the facility was determined to be an economic problem. The set-up cost has shown to be very high, its economic production range is undetermined as the technology is still in the infancy development stages. From the laboratory research, the by-product capability is very poor and the start-up time is very long. So far this technology has not yet been deployed for commercial use.

3) Molecular Sieving (Adsorption Technology)

Molecular sieveing or adsorption technology processes are based on the ability of some natural and synthetic materials to preferentially adsorb gases. These materials are called adsorbents. Molecular sieves are used as adsorbents for gases and liquids. Molecules small enough to pass through the pores are adsorbed while larger molecules are not. It is different from a common filter in that it operates on a molecular level and traps the adsorbed substance.

The adsorption processes rely on the fact that under high pressure, gases tend to be attracted to solid surfaces, or "adsorbed". The higher the pressure, the more gas is adsorbed; when the pressure is reduced, the gas is released, or desorbed. Pressure swing adsorption (PSA) processes can be used to separate gases in a mixture because different gases tend to be attracted to different solid surfaces more or less strongly. If a gas mixture such as air, for example, is passed under pressure through a vessel containing an adsorbent bed of zeolite that attracts nitrogen more strongly than it does oxygen, part or all of the nitrogen will stay in the bed, and the gas coming out of the vessel will be enriched in oxygen. When the bed reaches the end of its capacity to adsorb nitrogen, it can be regenerated by reducing the pressure, thereby releasing the adsorbed nitrogen. It is then ready for another cycle of producing oxygen-enriched air. Vacuum pressure swing adsorption (VPSA) lower the pressure in the tank to sub-atmospheric levels, hence improving the regeneration process. On the other hand we have temperature swing adsorbers (TSA) where temperature differential is used to adsorb and desorb the adsorbate.

PSA devices are best suited for processes that do not require extremely high purities of oxygen (less than 95 percent). However, the PSA's can achieve as high as 99.9 percent

purity but at a significant cost as compared to achieving 99.5 percent purity. PSA devices are best suited for small volumes of oxygen production, typically on the order of 200 tons/day.
Since the output of oxygen is largely controlled by the bed size in the PSA systems, costs rise linearly when higher volumes of oxygen are required. PSA devices take a few minutes to start-up, and it has very good safety record. Molecular sieve technologies have shown to have the lowest energy requirements when compared to other air separation technologies [13] [15].
Carlos Grande's [15] research works has shown that PSA in gas separation is a better solution which can be enhanced by having good interaction between material science and process engineering. He too has observed that the biggest challenge is in the development of cyclic strategies that can improve performances of the PSA. In as much as the process is very flexible, its process complexity has been a major issue in the deployment of the technology in various fields [15]. The usability of by-product nitrogen in PSA systems is limited because the nitrogen will have significant levels of oxygen [15]. This technology is semi-mature with room for technology improvements. Advances made in PSA is in technically in two domains, firstly in material sciences for adsorbent development and in engineering through development of new and more efficient ways to regenerate the adsorbent[15].
Research carried out by Liu Meng et all [29] has shown that in packed bed column adsorption the concentration and temperature of feed air strongly influence the equilibrium adsorption. The best fit has to be found for appropriate use with minimal energy cost. An increase in temperature reduces adsorption rate and vice versa. An increase in pressure on the other hand increase adsorption rate and capacity of the adsorbent.
The other drawback seen is the sequential arrangement of valves for adsorption and desorption which in the field has shown to be a problem with break downs being experienced many times. This is through observation and remarks made by the technical team at Laikipia Airbase Department of Defence nitrogen production facility using molecular sieve. Also Ma-bati Rolling Mills have a molecular sieve nitrogen generator and they experience the same too. Another big drawback of such systems is the production of by-products that are not usable.

III. Gaps

The major challenge identified by many researchers [25][26][27] in non-cryogenic oxy-gen production is the production of high purity oxygen, cost, number of pumps and compressors, and energy requirements. The major cost component is the number of components required and energy consumption and requirements to run these facilities. Pure oxygen requirements are on the rise and there is need to have this oxygen at a low cost, low maintenance production facility, ease of start and stop operation.

The research works by Jan Mletzko and others [28], the CO_2 purity for CCS can be improved by having O_2 purity greater than 95 percent. Also, research work by Alexander Dowling et al [30], were able to corellate the purity of CO_2 with the purity of O_2 fed in, in as much as they had lingering questions on the optimal O_2 purity from the air separation unit (ASU), though they concurred anything greater than 95 percent will be best.

Getting the right cyclic strategy is a challenge in that the right matrix has not been well established. This affects the sequential arrangement of valves and getting the right sequence control.

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The other gap seen affecting the non-cryogenic oxygen concentrator is the usability of the by-products. In all cases the by-products are exhausted back to the atmosphere which is a loss to the optimization of the process.

IV. Conclusion

From the literature review it is found out that oxy-fuel combustion is the way to go in greenhouse gas emission control mechanism. Therefore the oxygen produced for oxy-fuel combustion or gasification process should overall be cheap and from a process that is not complex and onsite.

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