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# Removal of Carbon Dioxide Gas from the Exhaust Gases Generated at the Takoradi Thermal Power Station

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**Abstract:** Takoradi Thermal Power Station (TTPS) generates electricity by burning fossil-fuel and hence generates also greenhouse gases especially carbon dioxide, which is vented into the atmosphere. These greenhouse gases are pollutants known to cause global warming. A method for the removal of carbon dioxide gas from the exhaust gases generated at TTPS is proposed in this research. It aims at reducing the plant's carbon dioxide emission into the atmosphere and hence reducing the plant's rate of pollution the atmosphere. The method employed is a modification of a method known as the Fluor Daniel ECONAMINE FG process. This method removes carbon dioxide from exhaust gas by using an amine solution which comes into "contact" with the exhaust gas in a counter-current manner. This method has been applied by 23 companies which produce $CO_2$ on a large scale. However, before TTPS apply this method a cost feasibility study is recommended.

**Key words:** Carbon dioxide, Diethanolamine (DEA), Diisopropanolamine (DIPA), Fluor Daniel ECONAMINE FG, greenhouse gases, global warming, Methyldiethanolamine (MDEA), Monoethanolamine (MEA)

## INTRODUCTION

Carbon dioxide ($CO_2$) capture and storage (CCS) is increasingly gaining recognition as a viable technology option for the mitigation of greenhouse gas emissions from large stationary sources such as power plants (Botero *et al.*, 2008). According to the International Energy Agency (IEA), the importance of CCS as an emissions reduction technology could rank second only to energy efficiency improvements by 2050 (Anonymous, 2006). The capture of $CO_2$ from power plants may be carried through separation of carbon either from the fuel (pre-combustion) or from the exhaust, the latter further differentiated according to whether pure oxygen (oxyfuel combustion) or ambient air (post-combustion) is used as an oxidant.

Post-combustion capture based on chemical absorption with aqueous amines is considered to be an attractive $CO_2$ capture option given its past commercial deployment in other industries such as natural gas processing, hydrogen and ammonia manufacturing (Botero *et al.*, 2008).

At the first international conference on carbon dioxide removal held in 1992, several studies were presented in relation to the $CO_2$ removal from power generated systems. At the conference the International Energy Agency (IEA) released several publications in which proposals on methods of $CO_2$ removal methods were stated. Among these proposals was the method known as "combined $CO_2$ and steam cycle which is an extension of the humid air turbine (HAT)", but most of these focused on $CO_2$ abatement from coal fired power plants (Rønning *et al.*, 1998).

During the increasing discussion of possible climate changes caused by the increase of the carbon dioxide concentration in the earth's atmosphere (greenhouse effect), which is attributable primarily to the burning of fossil fuels, such as natural gas, mineral oil and coal, there is an increasing range of proposals being put forward as to how, for example, in fossil-fired power plants, the carbon dioxide can be removed from the flue gases of the boiler or exhaust gases from gas turbine plants on an industrial scale before it is released into the atmosphere.

Among these was a proposal for removing carbon dioxide from a gas which contains carbon dioxide using a granular metal oxide, which is converted into a metal carbonate by absorbing carbon dioxide and is converted back into the metal oxide by subsequent removal of the carbon dioxide. The granular powder is either conveyed back and forth in a cycle between a fixation tower and a decomposition furnace or two similar devices with a solid powder bed are used alternately to absorb and release the carbon dioxide by switching between the devices. A drawback of this method is that the device, into which the carbon dioxide is released, again, must in each case be operated as an externally heated furnace (Schimkat *et al.*, 2003).

In another proposal, the flue gases from the fossil-fired boiler of a steam power plant is brought 'into contact' in counter-current with a liquid which absorbs

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carbon dioxide and contains, for example, an alkanolamine. The carbon dioxide which is absorbed by the liquid is removed from the liquid again at a different point in the liquid cycle and is then liquefied. The liquid cycle together with the necessary absorption and regeneration columns requires a substantial outlay on plant engineering (Schimkat *et al.*, 2003).

**General procedure for $CO_2$ removal:** The development of techniques for the separation and capture of $CO_2$ is considered to be one of the highest priorities in the field of carbon sequestration science. The technology for separation of $CO_2$ from flue gas or from other gaseous streams using chemical absorption has existed and been in use for decades (Allen *et al.*, 1933). To date, chemical absorption is the only technique that has been used commercially to capture $CO_2$ from flue gas. The general method involves exposing a gas stream to an aqueous amine solution which reacts with the $CO_2$ in the gas by an acid-base neutralization reaction to form a soluble carbonate salt (Maddox, 1974; Strazisar *et al.*, 2001):

$$2\,(R\text{-}NH_2) + CO_2 + H_2O \rightleftharpoons (R\text{-}HN_3)_2\,CO_3$$

where,

$$R = CH_3CH_2OH \text{ (ethanol)}$$

This reaction is reversible, allowing the $CO_2$ gas to be liberated by heating in a separate stripping column as described by the Fluor Daniel ECONAMINE FG Process. Therefore, the major advantage to this technique is that, in the ideal situation, the amine is not consumed and may be continuously recycled through the process.

The amine used in this process is most commonly one of several alkanolamines including monoethanolamine (MEA) as used by the Fluor Daniel ECONAMINE FG Process, diethanolamine (DEA), methyldiethanolamine (MDEA), or diisopropanolamine (DIPA).The technology was originally developed not for the purpose of carbon sequestration, but in order to "sweeten" natural gas streams by removing $CO_2$ (Maddox, 1974). More recently, it was successfully adopted for recovery of $CO_2$ from flue gas of coal-fired electric power generating plants (Arnold *et al.*, 1982). In this case, rather than $CO_2$ sequestration, the $CO_2$ has been used for commercial purposes such as enhanced oil recovery and the carbonation of brine as well as food industry uses. Currently there are three electric power generating stations in the U. S. that capture $CO_2$ from flue and six other major flue gas $CO_2$ capture facilities worldwide. All nine use MEA as the chemical absorbent (Herzog, 1999).

There is only one operation in the world that performs $CO_2$ separation for the purpose of sequestration.

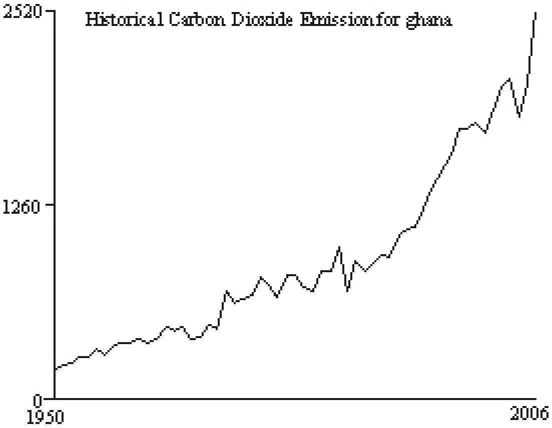


Fig. 1: Ghana's $CO_2$ emission versus time in years (Source: Anonymous, 2009)

Statoil's Sleipner plant separates about 2,800 tons of $CO_2$ from a natural gas stream daily using chemical absorption and injects it into a saline aquifer below the North Sea (Hammerstad, 2000).

**Carbon dioxide emissions in Ghana:** Ghana generally enjoys 'clean' atmospheric conditions. However, emissions from point sources such as vehicles, industries, and dusts from untarred roads, etc. tend to create atmospheric pollutants within their immediate environments. The most abundant greenhouse gas produced and emitted in Ghana is $CO_2$. There are $CO_2$ sinks in the forested and the reforested land. The trend of the total $CO_2$ equivalent removal sinks, however, shows a significant decline of about 49% from 1990 to 1996. There is fear that the rate of deforestation will offset net $CO_2$ removal as forests, which serve as sink for excess $CO_2$, are being depleted (Tamakloe, 2009).

Annual carbon dioxide emissions per capita emissions for Ghana from 1950 to 2006 are given in the Fig. 2. All emission estimates are expressed in thousand metric tons of carbon while per capita emission estimates are expressed in metric tons of carbon. The emissions considered include carbon emissions from fossil fuel combustion, cement manufacture and gas flaring.

From the values given in Fig. 1, it is evident that carbon dioxide emission in Ghana has been increasing. This implies that Ghana's contribution to global warming is also increasing. Fig. 1 and 2 give the trend of carbon dioxide emission in Ghana. The horizontal axis represents years from 1950-2006 and the vertical axis represents total $CO_2$ emission (in 1000 metric tons) and $CO_2$ emission per capita (metric tons) respectively for Fig. 1 and 2 of the country.

On average carbon dioxide emission increased steadily in values from the beginning of the 1950s through to the end of the 1980s (Fig. 1). There is a rapid increase

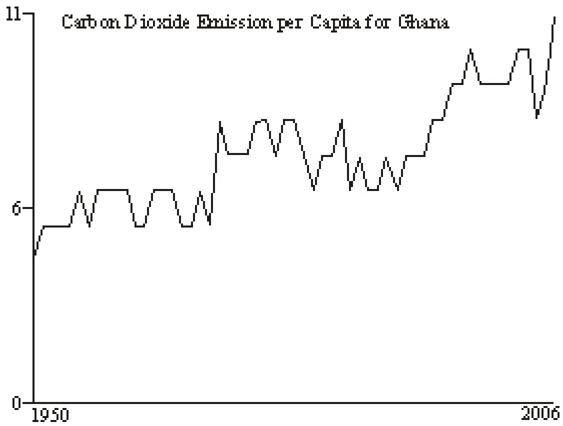


Fig. 2: $CO_2$ emission per capita versus time in years (Source: Anonymous, 2009)

from the beginning of the 1990s and even more rapid increase from 1998 to date. This later trend from 1998 may be attributed to the introduction of thermal power generation of electricity in Ghana from 1997. That is since the establishment of the Takoradi Thermal Power Station, carbon dioxide has increased very sharply.

Also, Fig. 2 establishes the fact that even though the population of Ghana is increasing, carbon dioxide emission is increasing at a rate faster than that of the population and hence $CO_2$ emission per capita is also increasing.

## MATERIALS AND METHODS

**Study area:** Power generation in Ghana has been an issue of public concern given the number of power crises the country has gone through in recent times. It was in anticipation of such occurrences that the government established the Takoradi Thermal Power Station (TTPS) to supplement the hydropower generation plants at Akosombo and Kpong. The Takoradi Thermal Power Station comprises the Volta River Authority (VRA) portion and the Takoradi International Company (TICO) portion located in the Sekondi Takoradi Metropolitan Area (Fig. 3). The VRA portion is the subject of discussion in this study.

The Sekondi Takoradi Metropolitan Area, with Sekondi as the administrative capital, occupies the south-eastern part of Western Region. It shares boundaries with Ahanta West, Mpohor Wassa East and Komenda-Edina-Eguafo-Abrem Municipal. It is located on the coast, about 200 km west of Accra. This makes it the smallest, but easily the most highly developed of the 13 districts of the Western Region. Indeed, it is the third largest metropolis in the whole of Ghana (Anonymous, 2010a). At 4º 55′ 0″ N, 1º 46′ 0″ W Takoradi is the largest city closest to the Equator and the Prime Meridian, making the city the most central location on the world map. The closest land to the Equator, Prime Meridian, and Sea Level is Cape Three Points, about 80 km west of Takoradi (Anonymous, 2010b).

Sekondi-Takoradi is one of the hubs of industrial activities in Ghana. It is the third most industrialized city in the country. It is one City the Government is counting on to lead the industrial revolution in the Country because of its seaport. The city can boast of hosting some of the big manufacturing industries in the country. However commerce continues to be the dominant sector of the economy with 33% of the population engaged in buying and selling. At the National economic level, buying and selling still dominates the economy with 30% engaged in the sector followed by agriculture 20%, Manufacturing 18% and social services 18%. A large and growing population of skilled and semiskilled persons provides bases and market for a wide range of goods and services.

To make the economy more vibrant, various measures are being put in place to attract investments both local and foreign. They include the expansion of the infrastructure base, provision of firm investment guarantees, reduce costs as well as cutting down delays in setting up businesses in the Metropolis and the Country as a whole (Anonymous, 2010c).

**The VRA section of the plant:** The VRA section of the plant is a 330 MW combined cycle plant made up of two 110 MW combustion Turbines and one 110 MW steam turbine (ST). The complete combined cycle plant comprising Combustion Turbine Generators One and Two (CTG 1 and CTG 2) with Heat Recovery Steam Generator (HRSG) which became operational in 2000 (Badger, 2007). It is a dual fuel plant. Distillate Fuel Oil (DFO) is currently used for the start-up and shut-down operations of the plant while Light Crude Oil (LCO) is used for the rest of the operations. The reported overall plant efficiency in the combined cycle mode is between 39 and 43% (Yawson *et al.*, 2007).

The Takoradi Thermal Power Station is a plant which generates electrical power by burning fossil fuels. The exhaust gases that are generated as a result of the generation process contains some amounts of greenhouse gases especially Carbon dioxide ($CO_2$). No matter how insignificant it is when it is looked at on the global scale, it also contributes to global warming.

The company knowing the effects of these gases when vented out into the atmosphere is doing its best to minimize the emission of carbon dioxide into the atmosphere by treating its fuels to make them as clean as possible. The company also uses demineralised water in the production of steam for its steam turbine. The effect of these actions on the $CO_2$ reduction is very much insignificant. Therefore the company is planning to use in the near future Liquefied Petroleum Gas (LPG) to fire its


Fig. 3: Map of Ghana showing the location of Sekondi-Takoradi

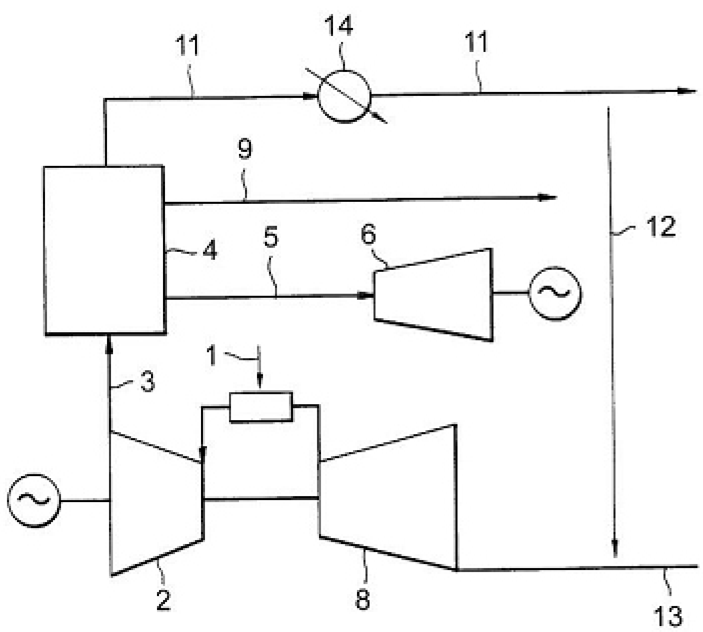


Fig. 4: Heat recovery and power generation cycle (Source: Rønning *et al*., 1998)

turbines since LPG burns very clean and produces very little amounts of greenhouse gases.

These approaches taken by the company show how important it is for the company to eliminate the greenhouse gases that are vented out into the atmosphere. Since the above considerations have not been so successful, a more significant method and approach will be proposed in this study.

**The fluor daniel ECONAMINE FG process:** The Fluor Daniel ECONAMINE FG Process relates to a method for removing and preventing emissions of $CO_2$ into the atmosphere from exhaust gases from gas turbines for the production of oil and gas. The process is summarized in the following steps:

- Natural gas and air are introduced into a gas turbine in which natural gas is burnt and converted into mechanical energy
- The exhaust gas from the gas turbine is passed through a heat recovery unit for recovery of the heat content in the exhaust gas
- After emitting heat in the heat recovery unit whereby the temperature of the exhaust gas has been reduced to between 20-70ºC, the exhaust gas is passed to an absorption column containing an absorption liquid, where the $CO_2$ is absorbed in the said liquid, and purified exhaust gas, essentially free of carbon dioxide, is vented to the atmosphere
- The absorption liquid containing $CO_2$ is passed to a stripping column where the $CO_2$ is removed from the absorption liquid by heating to a temperature of 120-150ºC
- The regenerated absorption liquid which is essentially free of $CO_2$ gas is passed to a compression stage for compression and utilization.

This method is characterized in that approximately 40% of the exhaust gas is recycled to the compressor air inlet of the gas turbine before the exhaust gas is passed to the absorption stage (Rønning *et al.*, 1998).

**Detailed description of the fluor daniel ECONAMINE FG process:** Fuel enters into the combustion chamber of the gas turbine (2) and it is burnt to produce flue gas (3) after it has been expanded through the gas turbine (2). The exhaust gas (3) then enters the heat recovery steam generator (HRSG). The HRGS (4) is designed for superheated steam production at two pressure levels (40 bar and 4 bar). The high pressure superheated steam (5) is journeyed to a steam turbine (6). The steam turbine is coupled via a gear to an electrical generator which provides the absorption and compression unit and plant platform with electricity (Fig. 4).

The steam turbine produces approximately 3 MW of “surplus” energy per gas turbine which can be utilized for other purposes on an offshore platform. The low pressure steam (9) is used to heat the stripping column reboiler.

In other to reduce the volume of the exhaust gas entering the absorption column and reducing the size and weight of the column, the gas turbine is operated with recycling of exhaust gas. The exhaust gas (11) leaving the HRSG (4) is cooled to 30ºC and 40% of the total volume is recycled (12) and mixed with fresh air between the air filter and the compressor inlet. The principal limitation of recycling is the oxygen content of the combustion air. Problems with instability and quenching of the flame may occur if the oxygen content is too low.

The exhaust gas from the heat recovery (11) and power generation units pass through an exhaust gas cooler (14) and an exhaust gas blower (15), Fig. 5, before entering an absorption column (tower). Through the absorption column (7), the carbon dioxide content of the exhaust gas (11) is removed and absorbed by means of a chemical (an amine) inside the column (Fig. 5).

The chemical (amine) used for the $CO_2$ removal is MEA ($CH_3CH_2(NH_2)OH$) and the temperature inside the absorption column is in the range of 20-70ºC. The chemical reaction between the amine (MEA) and the $CO_2$ (Maddox, 1974) is:

$$2(R\text{-}NH_2) + H_2O + CO_2 \rightleftarrows (R\text{-}NH_3)_2CO_3$$

This reaction is reversible and the equilibrium can be altered by altering the temperature. Hence at low temperatures in the range of 20-70ºC as in the absorption column, the equilibrium shifts to the right and the forward reaction is favoured hence $CO_2$ is absorbed by the MEA (18) in Fig. 6. At high temperatures usually in the range of 120-150ºC, the equilibrium shifts to the left and the reverse reaction is favoured hence the MEA (18) gives off the carbon dioxide.

Inside the absorption column (7) are gas absorption membranes (19). The gas absorption membranes (19) are membranes which are employed as contacting devices between the exhaust gas (17) inside the absorption column (7) and the MEA (18). The separation is caused by the presence of the absorption liquid (MEA) on one side of the membrane which selectively removes the carbon dioxide from the exhaust gas on the other side of membrane. The membrane (19) is intended to provide a contacting area which prevents mixing of the exhaust gas (11) and the absorption liquid (18). The membrane (19) however should be highly permeable to the carbon dioxide (16) which is required to be removed. The selectivity in the separation process is derived from the absorption liquid. A high selective separation can be achieved through an appropriate choice of the absorption liquid (Fig. 6).

The membrane should be porous and hydrophobic and its pores size should be about 0.2 µm in diameter. The membrane in combination with a suitable absorption liquid (in this case the amine MEA) enhances the $CO_2$ absorption process. As a result of the membrane’s hydrophobic nature and small pore size the exhaust gas and MEA flow are kept separate.

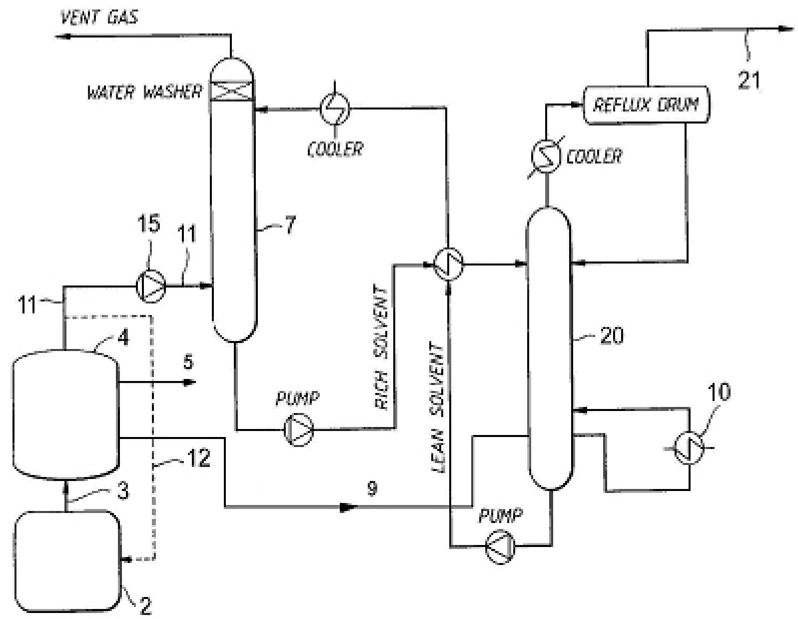


Fig. 5: Fluor daniel ECONAMINE FG process (Source: Rønning *et al*., 1998)

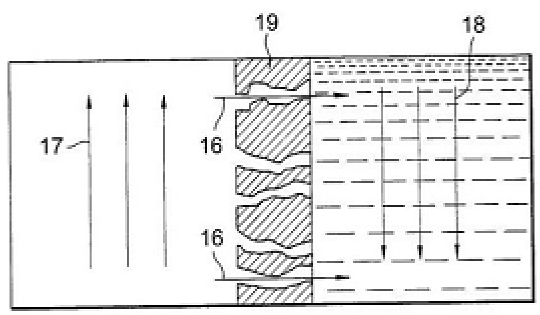


Fig. 6: Gas absorption membrane and separation process (Source: Rønning *et al*., 1998)

Now the $CO_2$ enriched MEA is passed to a stripper (20) (Fig. 5) where the $CO_2$ is released at temperatures of 120-150ºC.

The regenerated MEA is pumped back through a cooler into the absorption column for the absorption cycle to continue. In the cooler, the MEA is cooled to the required temperature before entry into the absorption column (7). The $CO_2$ which has been given of by the MEA in the stripping column (20) is passed to reflux drum where the $CO_2$ is dried and sent to compressor (21). The $CO_2$ at a temperature of about 120-150ºC, has to be cooled before entry into the reflux drum.

**Degradation of MEA in carbon dioxide capture:** A significant problem with the MEA absorption technique in its current form is the degradation of the amine over time. The by-products of MEA degradation are known to decrease the efficiency of $CO_2$ capture and have also been implicated in the corrosion of machinery (DuPart *et al*., 1993). In order to compensate for this degradation, current facilities include distillation of the amine to remove by products while continuously adding fresh amine to the system.

Unfortunately, this leads to increased material and waste disposal costs. In addition, degradation processes have forced the use of lower concentrations of MEA (usually less than 20%) leading to larger overall equipment size, higher solvent circulation rate, and therefore increased energy requirements for $CO_2$ regeneration from the rich amine (Leci, 1997). This increased energy requirement is especially significant since it increases the parasitic load on the power plant leading to increased fuel consumption, higher maintenance costs, and increased $CO_2$ production relative to the power output of the plant.

**Modification of fluor daniel ECONAMINE FG process for TTPS:** Some aspects of the Fluor Daniel ECONAMINE FG Process cannot be applied to the TTPS. The parts which may not be applicable to TTPS are considered in this section. These parts of the process will be modified to suit the application of TTPS.

**Recycling of exhaust gas:** In the Fluor Daniel ECONAMINE FG Process there is partial recycling of exhaust gas. This is done in order to reduce the volume of exhaust gas for treatment in the absorption process. The exhaust gas which leaves the HRSG is cooled to about 30ºC and about 40% of the total volume of exhaust gas is recycled and mixed with fresh air between the air filter and compressor inlet. At TTPS, the main goal of operation is to generate electricity and not to produce oil and gas hence when a fraction of the exhaust gas is recycled to the compressor air inlet and there is not enough oxygen to mix with the exhaust gas, the net power output of the gas turbine will be decreased due to high carbon dioxide content of the exhaust gas. Subsequently the net power output of the plant will be decreased. This is highly undesirable due to current energy demands of the people of Ghana.

Moreover, the operation of the gas turbines at TTPS, does not include recycling of exhaust gas, hence the above process will not be applicable to TTPS and subsequently it will be eliminated.

**Problem that will result from the elimination of the recycling process:** Recycling of exhaust gas in the Fluor Daniel ECONAMINE FG Process is essential in that it controls the volume of the exhaust gas entering the absorption column ensuring that there is a maximum removal of carbon dioxide from the exhaust gas. Again, it ensures that the maximum permissible pressure of the absorption column is not exceeded.

When this process is eliminated, the volume of the exhaust entering the absorption column will not be checked and this may result in the pressure increasing beyond the required value inside the absorption column. The required pressure in the absorption column is 11.386 bar.

**HRSG and the stripper column boiler:** The heat recovery steam generator for the Fluor Daniel ECONAMINE FG Process is designed such that it produces steam at two pressure levels. A high pressure superheated steam at 40 bar and a low pressure superheated steam at 4 bar. The high pressure steam is journeyed to the steam turbine which is coupled to a generator to generate electricity. The low pressure steam is journeyed to the stripper column boiler which provides the stripper column with the needed heat in order to separate the carbon dioxide from the MEA.

The heat recovery steam generator at TTPS is designed to produce steam at one pressure level that is a high pressure superheated steam at a pressure of 58 bar and all of it is journeyed to the steam turbine which is coupled to a generator to generate electricity. Hence no steam is sent to the stripper column boiler.

**Problem that will result from the unavailability of this process:** Since the HRSG at TTPS produces only a high pressure steam which is passed on to the steam turbine, there will be no steam to the stripper column boiler from which it will use to provide the heat required to heat the stripper.

**Rectification of problems:**

**Recycling of exhaust gas:** To control the volume of exhaust gas entering the absorption column and hence maintaining the absorption column pressure at 11.386 bar while simultaneously eliminating the recycling process, there will be another column which will act as a “silo” placed adjacent to the absorption column just before the entry of the exhaust gas into the absorption column. A flow control valve system and a pressure sensor (red spot on the absorption column) connected to the flow control valve will be attached to the absorption column (Fig. 7).

**Principle of operation:** Before the exhaust gas enters into the absorption column, it passes through the silo, then through the control valve and finally into the absorption column. As the volume of the exhaust gas increases as it enters the absorption column, pressure builds up inside the absorption column.

The maximum permissible pressure inside the absorption column is 11.386 bar and this should not be exceeded. The pressure sensor which is attached to the absorption column and connected to the flow valve measures the pressure inside the absorption column and sends signals (electronically) to the flow control valve.

The control valve then either cuts the flow of the exhaust gas into the absorption column (when the sensor measures pressure higher than the maximum value) or opens to allow flow of the exhaust gas into the absorption column (when the sensor reads pressures less the maximum).

When the valve closes, the exhaust gas which is still coming from the HRSG is stored temporarily by the silo. This stored untreated gas is later released from the silo into the absorption column when the treated exhaust gas in the absorption column leaves.

Such a pressure sensor can be the Bourdon Pressure Sensor (Fig. 8) because of its simple design and ease of operation.

**Bourdon pressure sensor:** This is basically a thin-walled closed tube with an oval cross section bent lengthwise into an arc of 270 to 300°. Pressure applied to the interior of the tube tends to distend the flattened tube into its original round shape, which causes the tube to straighten slightly. The movement of the tip of the tube drives a meter gear mechanism which moves the scale point to measure the pressure which can be transmitted electronically to the control valve. Shown in Fig. 9 is a butterfly control valve which can be employed.

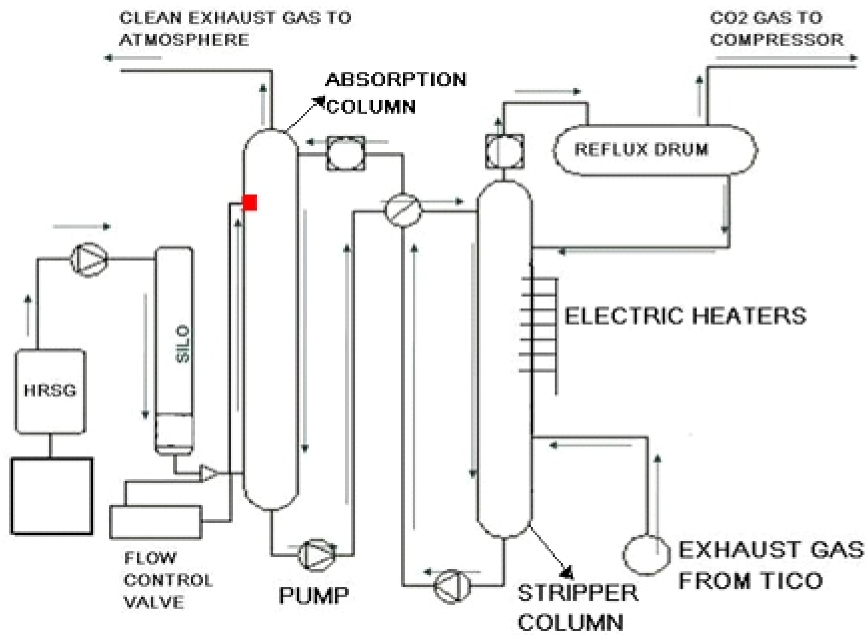


Fig. 7: Modified fluor daniel ECONAMINE FG process

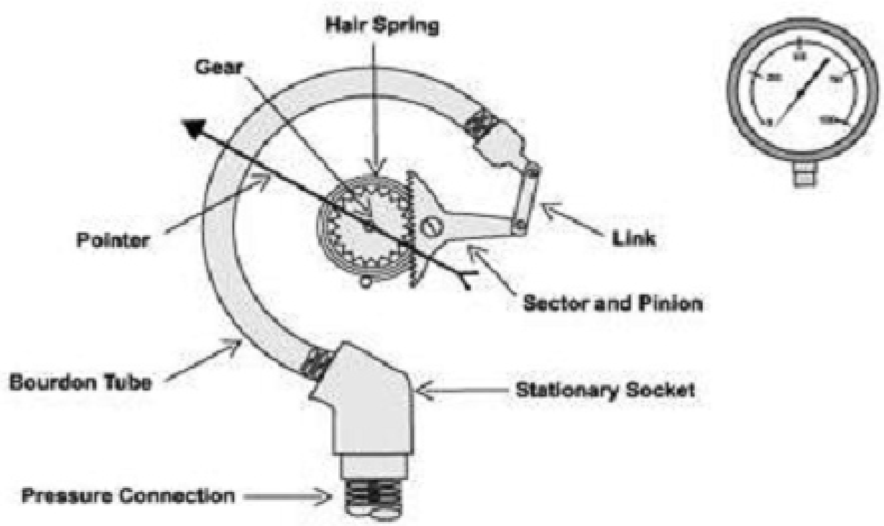


Fig. 8: Bourdon pressure sensor (Source: Anonymous, 2000)

**Butterfly control valve:** Butterfly valves are built on the principle of a pipe damper. The flow control element is a disk of approximately the same diameter as the inside diameter of the adjoining pipe, which rotates on either a vertical or horizontal axis. When the disk lies parallel to the piping run, the valve is fully opened. When the disk approaches the perpendicular position, the valve is shut. Intermediate positions, for throttling purposes, can be secured in place by handle-locking devices.

**HRSG and the stripper column boiler:** Since there will be no low pressure superheated steam to heat the stripper column, alternative for heating the absorption column must be adopted. Two alternatives are available namely:

- By the use of electric heaters
- With help from the Takoradi International Company (TICO)

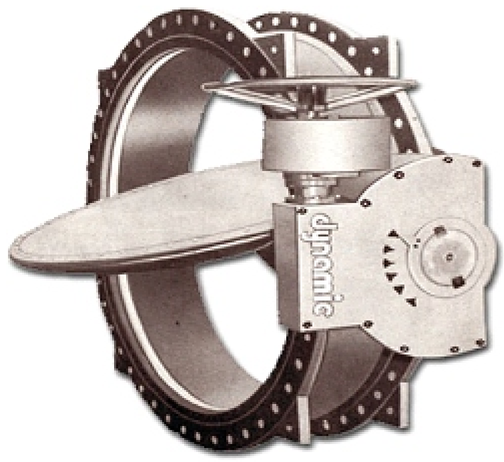


Fig. 9: Butterfly control valve (Source: Anonymous, 2000)

Electric heaters which are capable of heating to temperature betweens 120-150ºC can be installed as shown in Fig. 7 at reasonable intervals around the circumference of the stripper column and this can heat up the stripper column and hence carbon dioxide can be removed from the exhaust gas. This method is simple and easy but can increase total operational cost of the plant.

The Takoradi International Company (TICO) is a private company which also generates electricity by burning fossil-fuels. It is located on the premises of TTPS. TICO uses the simple cycle method to generate electricity and hence the exhaust gas generated there is vented out into the atmosphere.

If there could be a compromise between TTPS and TICO, TTPS can use the exhaust gas generated at TICO to heat the stripper column. This procedure may require complicated plant engineering, which can be cumbersome and will increase the size of the plant very much significantly but once it has been done, the operational cost of the plant will be less compared to the first option.

Looking at the two scenarios, incorporating both on the stripper column can be profitable to TTPS once it has been completed. When TICO is in operation, their exhaust gas will be used to heat the stripper and when TICO breaks operation (perhaps for maintenance purposes), TTPS can switch to electric heaters to heat the stripper column.

## DISCUSSION

The removal of the partial exhaust gas recycling process in the Fluor Daniel ECONAMINE FG Process and the subsequent introduction of a column known as the 'Silo' placed adjacent to the absorption column will ensure that the volume of exhaust gas is controlled thereby ensuring that the maximum volume of carbon dioxide is removed and at the same time the maximum permissible pressure of the absorption column is maintained as required by the original design. Again, it ensures TTPS is able to meet its power generation requirement since no gas will be diverted into the compressor air inlet for mixing with fresh air as required by the oil and gas industries.

The tapping of exhaust gas from TICO for heating the stripper column boiler or the use of electric heaters for the same purpose ensure that TTPS will not be required to completely change their HRSG to meet the requirement of the existing design. Either of these two modifications will ensure that the desired steam for plant power production is maintained and also ensure that the needed heat for heating the stripper column boiler to separate the carbon dioxide from the MEA is maintained.

## CONCLUSION

These modifications made on the Fluor Daniel ECONAMINE FG Process, will remove carbon dioxide from the exhaust gases generated at TTPS when it is incorporated into their system. Hence their carbon dioxide emission levels will greatly improve. This method removes between 85 - 95 % of carbon dioxide from exhaust gases. Hence a much cleaner and safer exhaust gas will be vented into the atmosphere.

## RECOMMENDATION

It is recommended that before TTPS adopts this method, a cost feasibility study should be done on the system. This will ensure that the company does not operate at a major loss.

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