



Studying the Designed Parameters of Carbonic Gas Production Unit's Solvents in the Way of Diesel Combustion

Amir Samimi^{*1}, Ali Bagheri², Sepehr Azizkhani¹, Sepanta Dokhani³, Ehsan Godini¹ and Babak Almasinia⁴

¹Department of Chemical Engineering, Shahreza Branch, Islamic Azad University, Shahreza, Iran.

²Department of Engineering, Saveh Branch, Islamic Azad University, Saveh, Iran.

³Young Researchers and Elite club, Shahreza Branch, Islamic Azad University, Shahreza, Iran.

⁴Development Unit, Isfahan Oil Refinery Company, Isfahan, Iran.

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ABSTRACT

Carbonic gas by chemical formula CO_2 and having acidic property (weak) has many uses as a primal material or intermediate. The first step in produce CO_2 gas is diesel combustion. Basically, the conventional methods of fuel combustion, the burning of excess air for complete combustion is used but the CO_2 gas production unit must be careful that the air was completely theoretical and no excess air is consider. Because of the separation of CO_2 from combustion gases, Mono Ethanol Amine (MEA) solvent is used. This solvent is an amine alcohol with the chemical formula $\text{CH}_2\text{OH}-\text{CH}_2\text{NH}_2$, that because of having alcohol structure is highly sensitive to oxygen And in contact with free oxygen, the alcohol agent becomes to aldehyde and acid That eventually led to the deterioration of the solvent can cause several side effects such as decrease in production rate, the loss of solvent, the phenomenon of corrosion, foam and ... This article examines the designed parameters of carbonic gas production unit's solvents in the way of diesel combustion.

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Introduction

Carbonic gas by chemical formula CO_2 and having acidic property (weak) has many uses as a primal material or intermediate and the trend in industry shows that can more optimistic about the future. In the early years of industrial development this gas were used as a refrigerant in cooling system but Today, with advances in science and industry and the emergence of new cost it uses as a primal material or supplementary in the various industries. So that despite reduction that consumption in steam refrigeration system, today the usage of that has an ascendant trend, Urea fertilizer production, raising the pressure in oil wells in the way of gas injection to increase recovery of crude oil, soft drinks, casting, fire control, industrial and waste water treatment plant and ... are major consumers of carbon dioxide in industry. In addition, the use of refrigeration power in the forms of solid (dry ice) or liquid (in free zing tunnels) or as refrigerants in refrigeration cycles yet its role in the cooling system is not lost.

Table 1: Mass Flow and the Molar Partial of Flows

Mass Flow of Streams (kg/hr)		Molar Partial of Streams
Input gas to the cleaning tower	2662	0.1575
Output gas from cleaning tower	2551	0.1577
Input gas to the sodaash tower	2551	0.1577
Output gas from sodaash tower	2551	0.1557
Input gas to the absorption tower	2551	0.1577
Input liquid to the absorption tower	31460	0.0065
Output gas from absorption tower	2032	0.00025
Output liquid from absorption tower	31980	0.01398
Input gas to the desorption tower	2952.5	0
Input liquid to the desorption tower	31980	0.01398
Output gas from the desorption tower	1472.5	0.25
Output liquid from the desorption tower	33460	0.0061
Output liquid from reboiler	31460	0.0065
Input gas to the gas cooler	1472.5	0.25
Input water to the converter	127042	0.0065
Input poor solvent to the converter	31460	0
Input poor solvent to the converter	31460	0.0065
Input rich solvent to the converter	31980	0.01398
Input water to the cooling tower	211900	0

Diesel Combustion

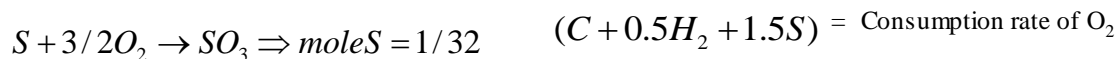
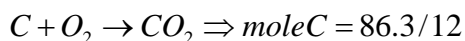
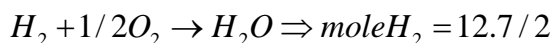
The first step in produce CO₂ gas is diesel combustion. Basically, the conventional methods of fuel combustion, the burning of excess air for complete combustion is used but the CO₂ gas production unit must be careful that the air was completely theoretical and no excess air is consider. Because for the separation of CO₂ of combustion gases, Mono Ethanol Amine (MEA) solvent is used This solvent is an amine alcohol with the chemical formula $CH_2OH - CH_2NH_2$, that because of having alcohol structure is highly sensitive to oxygen And in contact with free oxygen, the alcohol agent becomes to aldehyde and acid That eventually led to the deterioration of the solvent can cause several side effects such as decrease in production rate, the loss of solvent, the phe nomenon of corrosion, foam and ... Therefore, unlike other combustion systems (such as boilers, etc.) in this unit is strongly recommended to avoid the extra oxygen consumption and It is recommended that if complete combustion in the burner can not be achieved, its better the air be used lower than the theoretical because Injuries resulting from the incomplete combustion of fuel (of curse partially) the formation of soot and carbon monoxide in the system is much less than the excess air. Fuel used in this process, the diesel fuel specifications in the table 2 is shown.

Table 2: Iran Diesel Specifications

86.3%	C
12.7%	H
1.00%	S
0.87%	Sg(15C)
5×10^{-6}	$\delta(m^2 / s)$
180	B.P.E(C)
75	F.P.T(C)
43100	NCV(kj/kg)

Base: Fuel 100 kg

C: 86.3 % H: 12.7 % S: 1.0 %



$$(86.3/12 + 0.5 \times 12.7/2 + 1.5 \times 1/32) = 10.41 \text{kgmole } O_2 / 100 \text{kgFule} =$$

$$100/21 \times 10.41 = 49.57 \text{kmole} / 100 \text{kgFule} = \text{Consumption rate of Air}$$

$$100 \text{kgFule} \times \frac{550 \text{kgCO}_2}{\left(\frac{86.3}{12} \times 44 \text{kgCO}_2\right)} = 173.8 \text{kgFule} / \text{hr}$$

$$49.57 \text{kmole} / 100 \text{kgFule} \times 173.8 \text{kgFule} / \text{hr} \times 22.4 \text{Nm}^3 / 1 \text{kmole} = \text{Consumption rate of Air}$$

$$1930 \text{Nm}^3 / \text{hr} =$$

Since the pressure is 12.8 psi, the volume of the consumption air should be obtained on this base.

$$= 1930 \times 14.7 / 12.8 = 2216 \text{m}^3 / \text{hr} \text{ Acmal Air Consumption}$$

$$\%CO_2 = \frac{86.3/12}{(86.3/12 + 12.7/2 + 1/32 + 79/21 \times 10.41)} = 13.6\%$$

$$\%H_2O = \frac{12.7/2}{(86.3/12 + 12.7/2 + 1/32 + 79/21 \times 10.41)} = 12.04\%$$

$$\%SO_3 = \frac{1/32}{(86.3/12 + 12.7/2 + 1/32 + 79/21 \times 10.41)} = 0.06\%$$

$$\%N_2 = \frac{79/21 \times 10.41}{(86.3/12 + 12.7/2 + 1/32 + 79/21 \times 10.41)} = 74.3\%$$

Nm^3/hr : The gas volumetric flow rate

Volumetric flow rate of production gas: V

$$V \times 0.136 \times 44 / 224 = 550 kgCO_2 / hr \Rightarrow V = 2059 Nm^3 / hr$$

$$V_{CO_2} = 0.136 \times 2059 = 280 Nm^3 / hr$$

$$V_{H_2O} = 0.1204 \times 2059 = 248 Nm^3 / hr$$

$$V_{N_2} = 0.7436 \times 2059 = 1530 Nm^3 / hr$$

Blower Choosing

Blowers used to supply the required air for combustion of fuels generally are Eccentricity or a Revolving earrings type (Lobe Type). The eccentricity has lower initial cost and maintenance costs are less. But in terms of behavioral characteristics (Severe changes in the flow with the resistance against that) is not very good. Changing the air flow (low or high in the air to fuel ratio) can cause incomplete combustion and presence of excess air in the flame. Each one can create the side problems in the production process. Although the initial cost of a blower-type earrings have a higher But since the family of positive displacement blowers Changes in flow resistance in the face of fluctuations that can result from changes in water flow, and the solvent absorption was Sodaash. The shock towers or filling materials alter the flow resistance are negligible and therefore a blower with a fixed rate of return. So in designing this project blower is used to select the type of earrings.

Among the blowers in the Iran market, the Italian Robuschi company blowers that presented by Pars vacuum industry company in Iran has been selected. The require air in the combustion process $2216m^3$ in the real situation (the pressure is 12.8 equivalent (0.87 bar) that the pressure in the blowers output has to be 0.33 bar (g) equivalent 330 mbar (g). Refer to the company's catalog that has been provided at the end of this section, the RB101 at the rotational speed 1800 rpm at the 300 mbar (g) pressure has $2700 m^3/hr$ capacity and at the 400 mbar (g) pressure has $2650 m^3/hr$. Therefore, given the proximity of the pressure and capacity changes at the 330 mbar (g) can consider capacity as $2680 m^3/hr$.

Since the capacity of the blower has the linear relationship with rpm, so with the change of rotational speed with the help of pulley and belt, you can select the appropriate speed to achieve the desired capacity.

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} \rightarrow \frac{1800}{N_2} = \frac{2680}{2216} \rightarrow N_2 = 1488 rpm$$

Brake power (BHP) for $2650 m^3/hr$ capacity and 400 mbar (g) pressure is 36.1 that surely due to lower capacity and lower

pressure will be lower. However, according to Standard Electric Power And compliance with reasonable reliability in the electro motors choosing, the 38.5KW electro motor with the 1450rpm is advised that can create the desired speed at the blower with the help of pulley.

The Solvent Used

To separation the CO_2 in a wet environment that is slightly acidic, alkaline solvents used till be separated in the process (absorption) from the combustion product (flue). Absorption process is usually combined with chemical reactions and this increases the CO_2 absorption capability in the solvent. Chemical bond between the solvent and CO_2 , is a weak link, and because of the temperature will be Decomposition. And this allows the recovery $C CO_2$ of the solvent. Today, depending on the conditions of the separation process in various industries especially Gas Processing the different solvents is used that the most important of them are Alkanol amines, potassium bicarbonate and ...

According to the percentage of CO₂ in the combustion products of natural gas is very high (The CO₂ in the combustion products of fossil fuels, mainly between 10 and 15 now that the worst of natural gas, the amount of 5% and mostly less than 2% is reached) So according to the characteristics of the amine Mono ethanol amine details will be presented in detail in later chapters In all CO₂ gas units, Mono ethanol amine is used as a unique solvent.

Select a Suitable Solvent

Using Alkanol Amines to removal acidic gases (CO₂, H₂S) from natural gas has been beginning of the 1930s. This is due to the high chemical activity and their cheap cost. The hydrogen in ammonia is replaced by 1 to 3 basis alcoholic. In the primary methods of purification ammonia gas is used. But due to the volatility and other problems in the refining process is quickly abandoned, and today it has been replaced by other solvents, especially Alkanol Amines. Alkanol amines are transparent and colorless liquids and smells relatively steep (such as ammonia, with less steep) all the alkanol amines except tri ethanol amine (TEA) are chemically stable. And with the least problems and no disintegrate can even be heated to the boiling point. While (TEA) disintegrate at lower temperature of the normal boiling point (680 °F). At the table 3 the chemical structure of kinds of alkanol amine and at the table 4 chemical properties of mono, di, and the tri ethanol amine has are shown.

According to the Antoine equation (equation 1) which can be written as:

$$\text{Log}P = A - \frac{B}{(1 + C)}$$

P: steam pressure mm hg

T: boiling point °C

Table 3: Antoine Equation Constants of the Mono, Di, and Tri

TEA	DEA	MEA	
9.6586	8.12303	8.02401	A
4055.05	2315.46	1921.6	B
237.67	173.3	203.3	C

Table 4: Has Presented Some Acidic Characteristics of Alkanol Amines

TEA	DEA	MEA	
148.19	105.14	61.08	Molecular weigh
0.0063	0.0058	1.05	Steam pressure at 100F (mmHg)
41	58	100	Relative absorptive capacity

Mono ethanol amine acid gas absorption capability of the acidic gases (SO₂, CO₂) and don't have selected absorb ability for each one of above gases. Due to its low molecular mass in comparison with other Alkanol amines, acid gas absorption capacity per unit weight by the solvent is much higher. This causes saving the amount of solvent used in the acid gas removal system of fixed cost (Solvent consumption, dimensions of equipment such as absorption tower, and the Tower-free)and Current costs (The cost of pumping the solvent, heating the solvent preparing for the free process).High vapor in comparison with other Alkanol Amines causes in the CO₂ separation process of the solvent Greater amount of vapor by CO₂ exit from tower free that in separation process, can be retrieved that, with cooling the CO₂ gas and condensation of solvent vapor.

This problem is more undesirable effects on the absorption tower because the neutral gas in absorption tower is sent out of the system so has a little solvent which reduces the amount of solvent in the system and finally the increase will be offset. High ability to capture CO₂ in MEA leads High percentage of the combustion products are taken in the absorption tower. And a small amount of that exit by the neutral. In systems that are designed correct the amount of CO₂ in inert gas can be 0.05 $\frac{\text{Grain}}{\text{ft}^3}$ or 0.15 PPM.

Solvent Concentration

One of the important parameters in the design of the CO₂ gas-feed separation units is Select MEA concentrations used in the separation process. Obviously, with increasing solvent concentration Flow rate and size of equipment used and the system of pipes

and fittings, and the isolated towers, pumping systems and ... Decreases. Therefore, system designers have always tried to have high concentrations of solvents to reduce initial investment costs (Capital Cost) and expenses (Operating Cost).

With increasing concentration of the solvent system increases the risk of corrosion. MEA in terms of having the amino agent have alkaline property and therefore the ability to cause corrosion in the steel, it is even less of the water. Increasing solvent concentration, was increased the pH and therefore should reduce the risk of corrosion with increasing pH. But during the separation process none of above contents is true. But with increasing solvent concentration, the rate of corrosion in the system increases the contradiction must be capable of absorbing CO₂ ability in solvents with increasing solvent concentration. With increasing concentration of solvent especially in cases that CO₂ s percentage is high in the system feed, the CO₂ absorbing increase in the solvent and this causes the solvent PH decrease and corrosion risk increase in system. Therefore, in systems that are designed based on the application of high concentrations of MEA the composition of the corrosion inhibitors are used. Therefore the design of separation systems is governed by two main thinking:

- A) The use of solvents with low concentration and low alloy steels in the equipment constructing
- B) The use of solvents with high concentrations of compounds associated with the application of corrosion inhibitors

In the design of CO₂ production lines, the concentration of solvent used varies among different manufacturers however, in a limited range between 15-8 percent, is chosen.

According to studies performed on different production units of CO₂ most experts prefer to use the solvent concentration about 12 percent, Therefore, the concentration of solvent used in the design of these units is 12%.

Calculating the Solvent Flow

In calculating the flow rate of solvent used in the system it is necessary to first determine the following information:

- 1- Solvent concentration
- 2- The amount of CO₂ gas at the down of absorption tower
- 3- The amount of CO₂ that remained in the output solvent from Reboiler
- 4- The amount of CO₂ that should absorb in time unit

The concentration of solvent used (MEA) is 12% as said before.

Production capacity was 500 kilogram per hour, Due to the loss of CO₂ gas during the production process, the design capacity of 520 kg per hour is considered. In system designing it is assume that the amount of absorbed gas, about 75-80 percent of its value in the balance. But practically it is difficult to achieve the above values, with increasing concentration of the absorbing gas in the solvent, the absorbed process is not going easily and its amounts decrease, so in system designing its assumed about 60% of the value of the equilibrium amounts at the temperature and pressure of the absorption tower down. Decreased absorption causes of reduced risk of corrosion in the system.

$$P_{CO_2} = 1.05 \times 14.7 \times 0.136 = 2.1$$

$$t=40c=104F$$

According to the fig (1-8) at the equilibrium conditions:

$$\text{moleCO}_2 / \text{moleMEA} = 0.603$$

Assuming that 60% availability availability of adsorption at equilibrium conditions:

$$(\text{moleCO}_2 / \text{moleMEA}) = 0.6 \times 0.603 = 0.362$$

Depending on temperature conditions (pressure) in the free tower, always there will be amount of not separated CO₂ in the output solvent, amount of that can be 0.05-0.2 mol CO₂ per each MEA mol. The solvent temperature in free tower is 110° C (230F). Du to fig (A-9) the remain CO₂ in solvent is about 0.168 $\text{moleCO}_2 / \text{moleMEA}$. So the pure amount of absorbed CO₂ in absorber tower is:

$$\text{NetPick} - \text{up} = (\text{moleCO}_2 / \text{moleMEA})_{ow} - (\text{moleCO}_2 / \text{moleMEA})_m$$

$$\text{Net Pick-up} = 0.362 - 0.168 = 0.194$$

$$= 520 \text{ kg CO}_2 / \text{hr} = 11.82 \text{ mole CO}_2 / \text{hr} \text{ System capacity}$$

$$\text{mole MEA} / \text{hr} = \frac{\text{mole CO}_2 / \text{hr}}{\text{Net - Pick - Up}} = 11.82 / 0.194 = 60.93$$

$$60.93 \times 61.08 = 3721 \text{ kg MEA} / \text{hr}$$

$$= 3721 / 0.12 = 31012 \text{ kg/hr solvent flow 12\%}$$

Conclusion

Calculating the Temperature of the Output Gases from Exhaust

To calculate the temperature of output gases, it is necessary to write overall energy balance around the boiler.

1- Calculating the heat of combustion: (Q_1)

$$\text{NCV} = 43100 \text{ kJ/kg Fuel} = 10311 \text{ kcal/kg Fuel}$$

$$Q_1 = 10311 \times 173.8 = 1792052 \text{ kcal/hr}$$

2- Calculating the require heat for heating the pure solvent: (Q_2)

MEA enter with the 85°C from above the tower and exit with 110°C from the down of boiler.

$$T_{av} = 98^\circ \text{C} \Rightarrow C_{p_{MEA}} = 0.98 \text{ kcal/kg}$$

$$Q_2 = 31012 \times 0.98 \times (110 - 85) = 75974 \text{ kcal/hr}$$

3- Calculating the required heat to heating CO_2 : (Q_3)

The CO_2 with MEA enter with 85°C from the top of tower and will exit at 110°C from the top of the tower by water steam.

$$Q_3 = 970 \times 0.22(110 - 85) = 5324 \text{ kcal/hr}$$

4- The required heat to evaporate water and MEA in Reboiler: (Q_4)

$$\text{Re flux - Ratio} = \frac{\text{Mole MEA} + \text{Mole H}_2\text{O}}{\text{Mole CO}_2} = 4$$

$$T = 110^\circ \text{C} \xrightarrow{r_{xy}(A10)} \begin{cases} \text{H}_2\text{O} = 0.95 \\ \text{MEA} = 0.05 \end{cases}$$

$$M_{av} = 0.95 \times 18 + 0.05 \times 61.08 = 20.15$$

$$(\text{H}_2\text{O} + \text{MEA}) = \frac{520}{44} \times 4 \times 20.15 = 952.5 \text{ kg/hr}$$

$$\text{MEA} = 0.05 \times 952.5 \text{ kg/hr}$$

$$T = 110^\circ \text{C} \Rightarrow \begin{cases} \lambda_{MEA} = 215 \text{ kcal/kg} \\ \lambda_{\text{H}_2\text{O}} = 533.5 \text{ kcal/kg} \end{cases}$$

$$Q_4 = 904.9 \times 533.5 + 47.6 \times 215 = 492998 \text{ kcal.hr}$$

5- Heat loss from the body

It is assumed that heat loss from the body is 10% of heat of combustion of fuel in the burner.

$$Q_5 = 0.10 \times 1792052 = 179205 \text{ kcal.hr}$$

6- Required heat for separation CO_2 of MEA: (Q_6)

Each pound of CO_2 needs 825 BTU for separating of MEA

$$825 \text{ But / lb CO}_2 \Rightarrow Q_6 = 458.4 \text{ kcal / kg CO}_2 \times 520 \text{ kg CO}_2 / \text{hr} = 238368 \text{ kcal / hr}$$

The heat that use for combustion gases heating: (Q)

$$\text{Energy balance} \Rightarrow Q = Q_1 - (Q_2 + Q_3 + Q_4 + Q_5 + Q_6) = 116363 \text{ kcal/hr}$$

To obtain the temperature of output gases, guess a temperature as a initial temperature

$$T = 100C \Rightarrow \begin{cases} H_{CO_2} = 40.9 \text{ kcal/Nm}^3 \\ H_{H_2O} = 35.8 \text{ kcal/Nm}^3 \\ H_{N_2} = 31.1 \text{ kcal/Nm}^3 \end{cases}$$

$$H_T = 280 \times 40.9 + 248 \times 35.8 + 1530 \times 31.1 = 67913$$

If enthalpy obtained was equal with the thermal heating that spent for combustion gases heating, initial guess is correct. As can be seen, the obtained enthalpy is less than required heat for heating the combustion gases and in next guess the temperature should increase.

$$T = 200C \Rightarrow \begin{cases} H_{CO_2} = 86.1 \text{ kcal/Nm}^3 \\ H_{H_2O} = 72.5 \text{ kcal/Nm}^3 \\ H_{N_2} = 62.5 \text{ kcal/Nm}^3 \end{cases}$$

$$H_T = 280 \times 86.1 + 248 \times 72.5 + 1530 \times 62.5 = 137713$$

The required heat for heating combustion gases is more than the Enthalpy of combustion gases at 100°C and less than Enthalpy of gases at 200°C. Therefore, interpolation can be obtained the temperature of the output smoke.

$$T = 200 - (H_{200} - Q) / (H_{200} - H_{100}) \times 100 \quad \text{Real}$$

$$= 200 - (137713 - 116363) / (137713 - 67913) \times 100 = 169.4^\circ C$$

Calculate the thermal load of washing tower

$$\text{Fule - gas - int el} \Rightarrow \begin{cases} V_{CO_2} = 280 \text{ Nm}^3 / \text{hr} \\ V_{H_2O} = 248 \text{ Nm}^3 / \text{hr} \\ V_{N_2} = 1530 \text{ Nm}^3 / \text{hr} \end{cases}$$

According to the constituents of smoke, it can be considered equivalent to the air and calculate the humidity at output temperature 40°C

1- Mixture of smoke similar to the air

2 -30kilograms CO₂ will absorb in water in an hour

$$\frac{30}{44} \times 22.4 = 15.3 \text{ Nm}^3 / \text{hr} \Rightarrow 280 - 15.3 = 264.7 \text{ Nm}^3 / \text{hr}$$

The amount of water in the smoke output with supposition the similarities to air at 40 °C is about 0.049kgH₂O/kg dry air

$$= \frac{264.7}{22.4} \times 44 + \frac{1530}{22.4} \times 28 = 2432.5 \text{ kg} \quad \text{Flue dray gas}$$

$$= 2432.5 \times 0.049 = 119 \text{ kg/hr} = 119/18 \times 22.4 = 148.3 \text{ Nm}^3 / \text{hr} \quad \text{Water Content}$$

$$\text{Out - let - Flue - gas} \Rightarrow \begin{cases} T = 40^\circ C \\ V_{CO_2} = 264.7 \text{ Nm}^3 / \text{hr} \\ V_{H_2O} = 148.3 \text{ Nm}^3 / \text{hr} \\ V_{N_2} = 1530 \text{ Nm}^3 / \text{hr} \end{cases}$$

In the top tower is needed in addition the gas cleaning and separation of suspended particles such as soot, gas temperature reach to 40°C

Thermal load of tower: (Q)

$$Q=116363-(3004+19528+7985) =85836 \text{ kcal/hr}$$

It's assumed that the water enters to the tower with 30°C and exits that with 40°C

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