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Economics of wastewater treatment in GTL plant using spray technique

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Abstract

In a Gas-to-liquid (GTL) plant, significant quantities of CO_2 and reaction water are produced and various chemicals are used as intermediate treatment chemicals. The reaction water is contaminated by these chemicals which impair the pH and the related properties of the water. The pH has to be controlled in the effluent treatment unit before the water is re-used or released to the environment.

The overall aim of this investigation is to create a novel technique to address the problem of waste water treatment in GTL plants which will assist in the reduction of greenhouse gas (CO_2) emissions into the atmosphere.

A laboratory-scale effluent neutralisation unit for pH control utilising gas injectors was designed and built. The unit used the CO_2 produced as a by-product of GTL process as wastewater treatment chemical instead of the conventional Sulphuric acid. The quality of wastewater after treatment with CO_2 met the standards set by the state regulatory agency.

The economics of the new process shows a better payout period of 3.6 years for capital investment of $1,645 Million compared to 4.7 years for an existing plant layout with capital investment of $1,900 Million. The effects of increase in plant capacity showed a lower payback back of 2.8 years for plant capacity of 140,000 barrels/day (22258 m^3/day), 3.6 years for 34,000 barrels/day and 6.0 years for 12,500 barrels/day (1987 m^3/day) plant capacity.

The sensitivity analysis using crystal ball simulator with 'Microsoft Excel' shows that the annual revenue has the greatest effects on the NPV of the plant than the CAPEX and inflation rate.

Apart from the environmental benefits the process generates by reducing CO_2 emissions into the atmosphere, the study also concludes that the replacement of conventional Sulphuric acid (H_2SO_4) unit with CO_2 improves the economics of the plant.

Keywords: Wastewater treatment; pH control; Carbon dioxide injection; GTL plant.

1. Introduction

The Gas-To-Liquid (GTL) technology consists of a chemical conversion of natural gas into a stable liquid by means of the Fischer-Tropsch (F-T) process. This conversion makes it possible to obtain products that can be consumed directly as fuel (diesel, kerosene and gasoline) or special products such as lubricants.

In the 2006 IEA World Energy Outlook reference scenario, gas-to-liquids is forecast to increase from 8 billion m^3 in 2004 to 29 billion m^3 in 2010 and to 199 billion m^3 in 2030 [1].

The products that are derived from the GTL technology have two types of economic advantages:

1. Their transport cost is much less than that of the transport of natural gas, which due to its volume (that is 1000 times more than the volume of petroleum) does not only presents high transport costs but also requires specific assets like pipeline and cryogenic LNG ship.
2. The products present important environmental advantages compared to traditional products as they are derived from a clean fuel - natural gas.

Despite these advantages, GTL technology has two major setbacks. Firstly it is capital intensive. A typical GTL plant requires a capital cost ranging from $25,000 to $52,000 per barrel per day [2,3,4]. Secondly a conventional GTL reforming technologies and Fischer-Tropsch synthesis, especially those using iron catalysts are net generators of carbon dioxide as shown in reforming Equations 1 and 2.

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{1}$$

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2 \tag{2}$$

Figure 1 shows the emissions associated with various oil and gas processes including conventional oil, heavy oil, and GTL. The Figure shows that about 1150 kg of CO_2 is produced by a tonne of GTL product and based on over 20 GTL projects around the world, the volume of produced CO_2 calls for capture to avoid environmental emissions.

This work focuses on the in-situ utilisation of produced CO_2 from the reforming and Fischer-Tropsch reactions in GTL plant for wastewater treatment. This technology eliminates the process and design problems associated with the recycle of CO_2 either as feed or low energy fuel to the reformer. It will also eliminate the current use of sulphuric acid for pH control of the effluent and therefore reduce the operating costs of GTL plant and it will finally reduce the emission of CO_2 into the atmosphere.

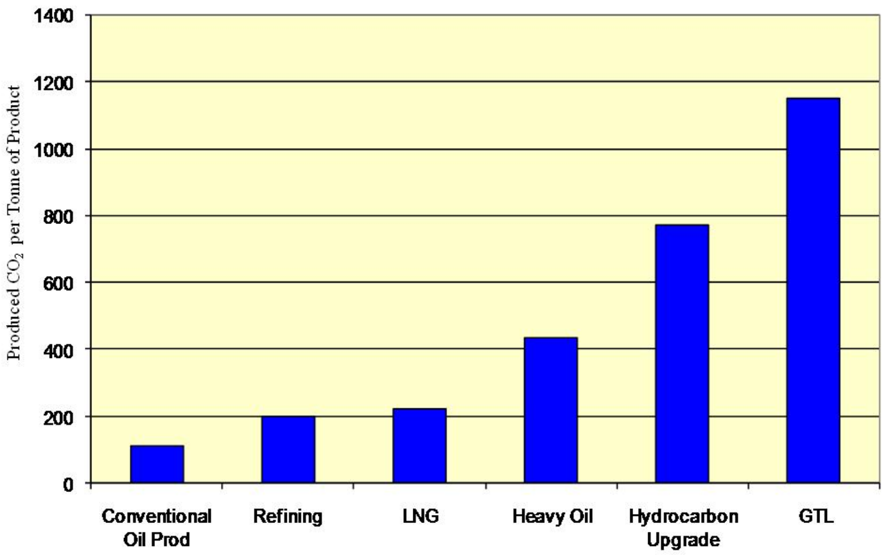

Figure 1. CO_2 emissions associated with oil and gas operations (Source: IEA/OCED)

2. Sources of wastewater in GTL plant

The hydrocarbon-free aqueous effluents which require pH adjustment come from the following six sources within a typical 34000 barrels GTL plant as shown in Figure 2.

These wastewaters contain a high concentration of dissolved solids with a pH range of 9 to 12. These wastewater streams are collected in the neutralisation basins. The basin has two compartments known as the main and the discharge compartments. The main compartment receives the untreated water and sends the water to the discharge compartment after treatment. The discharge compartment discharges the treated water to a safe location. The main compartment occupies about 75% to 80% of the total volume of 380 m^3. About 150,000 kg/h of waste water flow into the treatment plant while 149,868 kg/h of effluent is treated and discharge. The difference is lost due to evaporation.

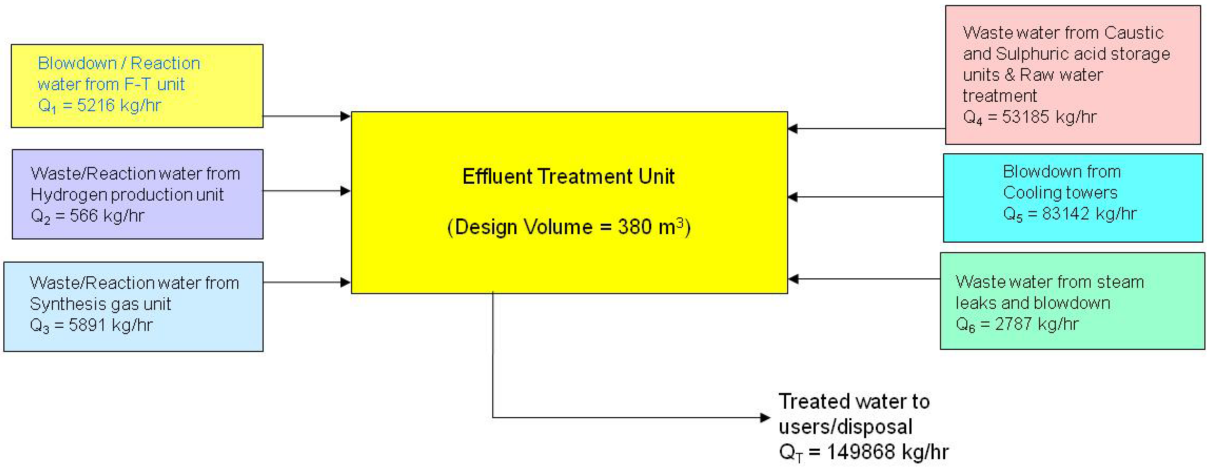

Figure 2. Sources of wastewater from GTL plant

3. Conventional method of wastewater treatment process

The first step in wastewater treatment is coarse screening to remove large materials such as rags, logs, sticks and cans. The effluent is then transferred to the secondary stage. The secondary stage is a biological treatment process. It removes soluble materials by mixing the wastewater with a coagulant. The coagulation is used to remove waste materials in suspended or colloidal form. After coagulation, the wastewater is sent to a gravity separator, clarifier unit to remove any remaining suspended solids. The resultant wastewater is further treated with oxidising and disinfecting agents to minimise the Bio-Oxygen Demand (BOD) level.

The final stage required in the treatment process is the addition of disinfectant to reduce microorganisms that remain in the treated water. The addition of chemical such as chlorine and acid injections for pH control are necessary to bring the water quality to the desired.

The pH adjustment chemicals regulate the pH to desired level of 7.0 before the water is re-used or discharged into the environment. In most plants, the pH control unit uses concentrated Sulphuric acid for pH control. The acid is a very corrosive and expensive chemical and therefore requires careful handling and special equipment selection. This treatment creates additional expenses in operating cost of the plant.

The Sulphuric acid supply is from external sources. It is stored on arrival at the plant site in the acid storage tank. Some quantity of the acid is transferred from the storage tank through an acid transfer pump into the acid mixing tank for dilution using distilled water. The diluted acid is finally pumped into the neutralisation basin via an acid dosing pump for pH control as shown in Figure 3. The chemical reaction between the alkaline wastewater and the sulphuric acid is written as shown in Equation 3.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O \tag{3}$$

After the neutralisation reaction, the wastewater with pH between 6.8 and 8.0 is released to the discharge compartment through a guillotine door. The discharge compartment has a pair of pump connected to it. It receives the treated water and pumps it to a safe location or recycles the water for re-use.

3.1 Proposed wastewater treatment process in GTL plant

The proposed treatment process will utilise the CO_2 produced as by-product from the reforming and Fischer-Tropsch units to neutralise the wastewater from the plant. Gas injectors are used to generate tiny CO_2 bubbles in the neutralisation basin by injecting CO_2 into the water (Figure 4). These gas bubbles form carbonic acid in presence of water as shown in Equation 4.

$$CO_2 + H_2O \rightarrow H_2CO_3 \tag{4}$$

$$H_2CO_3 + NaOH \rightarrow NaHCO_3 + H_2O \tag{5}$$

$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O \tag{6}$$

The carbonic acid formed, is used for pH control by neutralising the alkaline water as shown in Equations 5 and 6, instead of the expensive and corrosive sulphuric acid used in the conventional method. Equations 5 and 6 show that the neutralisation curves of the alkaline water by carbon dioxide will exhibit two neutralisation points. The first neutralisation point in Equation 5 produces sodium bi-carbonate salt which is very unstable. The unstable bi-carbonate salt finally neutralises to sodium carbonate. A typical wastewater quality after treatment with carbon dioxide is shown in Table 1.

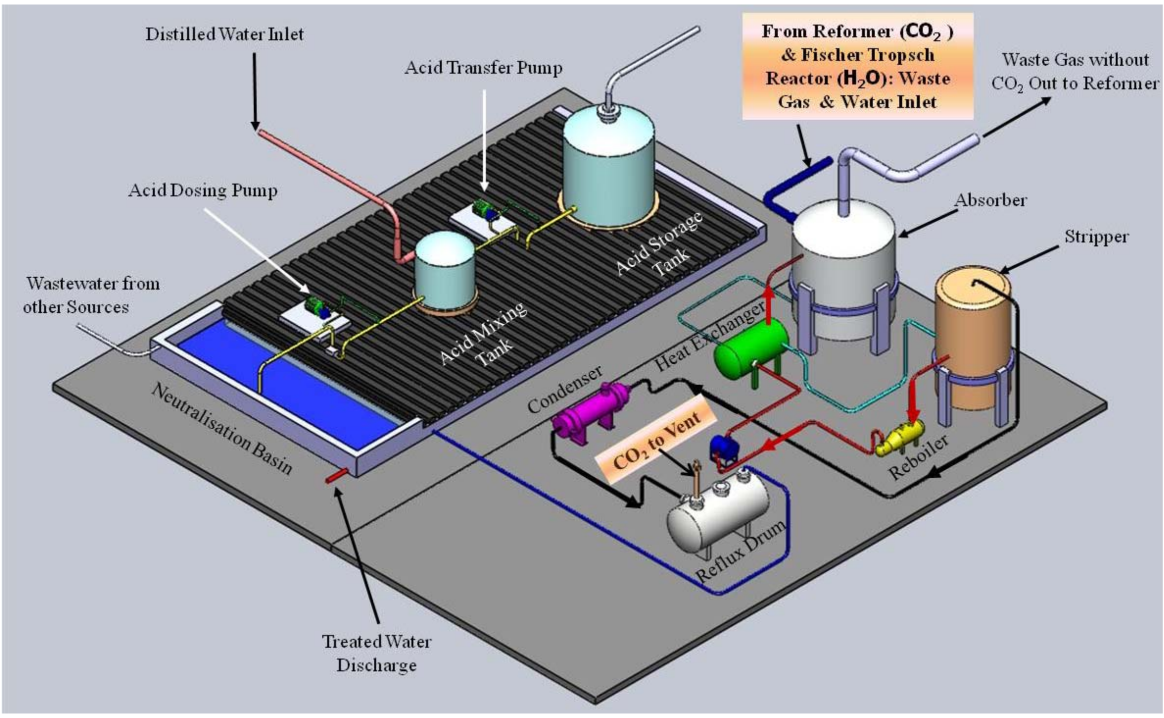

Figure 3. Schematic of conventional wastewater treatment using sulphuric acid

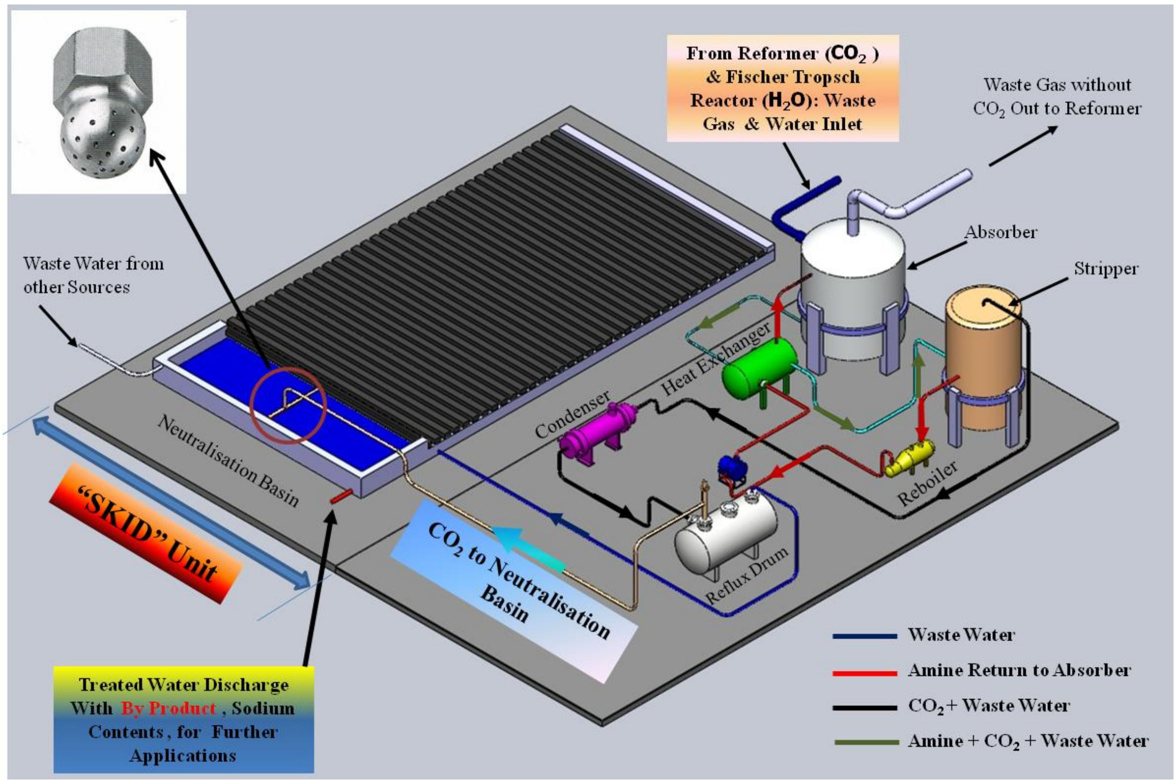

Figure 4. Schematic of the proposed wastewater treatment using CO_2 and atomiser

Table 1. A typical synthesis gas plant wastewater quality after treatment [5]

S/N	Parameter	FEPA(*) Limit	Wastewater quality after treatment
1	Temperature (^oC)	40	27.57
2	pH	6 – 9	7.56
3	Total Dissolved Solids (TDS) (mg/l)	2000	515.15
4	Oil (mg/l)	50	Nil
5	Heavy Metals (mg/l) (Ni, Fe, Zn, V)	3	1.49

4. Consideration of economic parameters

In order to conduct the economic analysis of GTL project, the following economic parameters were considered in this study.

- GTL plant has a capacity of 34,000 barrels of liquid product per day
- Estimated plant life of 25 years
- Plant operates at 330 days per year
- Discount rate is taken as 10%
- All costs were assumed to escalate at 3% every 5 years
- Feed gas volume is 340MMscf per day (1barrel = 10,000 scf of gas per day)

4.1 Total capital cost of GTL plant without CO2 recovery

The breakdown of GTL capital expenditure (CAPEX) from some organizations such as [6, 7] compared closely with each other. This study averaged the capital cost estimate for a GTL plant capacity of 34,000 barrels per day and estimated it to be $1900 Million dollar.

4.2 Estimation of non-feed costs

In absence of itemized costs, the non-feed cost is taken as a lump sum of 16% of the total capital investment [8]. Considering the GTL plant capital cost of $1.9 billion US dollars, the non-feed cost is estimated to be $304,000,000 per year.

4.3 Cost of raw materials (feed cost)

For a plant capacity of 34,000 barrels per day and running for 330 days in a year, the annual gas consumption will be 340,000 Mscf.

Assuming a heating value of 1000 BTU/Scf and cost of $0.25/MMBTU, the annual cost of natural gas will be $28,050,000. Steam consumption is estimated to be 9,627,728 Ton/yr at the cost of $0.15/Ton giving $1,444,160 while Oxygen consumption is 4813864 Ton/yr at the cost of $0.1/Ton to give $ 549,260. The costs of raw material are estimated to be $30,043,420.

The total operating cost for plant without CO2 integration is the addition of feed (raw materials) and non-feed costs. This gives annual OPEX as $334,043,420

4.4 Revenue from sales of GTL products

The typical GTL plant with a plant capacity of 34,000 barrels of liquid per day and which requires about 340 MMscf of feed gas is used in this study. The product breakdown from the plant depends on the process operating conditions and the catalyst used. The product breakdown which is used in this study is [9]:

- Diesel oil - 75% = 25,500 barrels of GTL product
- Naphtha - 20% = 6,800 barrels of GTL product
- LPG - 5% = 1,700 barrels of GTL product

The product pricing for GTL fuel is highly dependent on the proximity to the target market and it differs for different location. Considering the product yields stated above and the product price suggested by [10], the annual sales of GTL products are shown in Table 2.

Table 2. Annual sales of GTL products

Products	Percentage Product Distribution	Production (Bbls/day)	Price/ Bbl ($/Bbl)	Annual sales ($)
Diesel	75	25,500	138.18	1,162,784,700
Naphtha	20	6,800	105.42	236,562,480
LPG	5	1,700	68.04	38,170,440
Total	**100**	**34,000**		**1,437,517,620**

Using the product prices quoted above, the revenue from the GTL plant is estimated at about **US$ 1,437.52 Million/year.**

4.5 Total capital cost of GTL plant with CO_2 recovery

The modifications carried out in the unit involved the removal of Sulphuric acid storage tanks and transfer pumps while the change to CO_2 unit required the purchase of atomisers, valves and fittings, pipe and instrumentations. A typical GTL plant cost estimate with carbon dioxide recovery was estimated to be $1645.60 Million dollar.

4.6 Operating expenses of the plant with CO_2 capture and utilization

This second scenario uses the CO_2 that was produced in the plant, as a replacement for the acid in the conventional method. The CO_2 from the reforming and Fischer-Tropsch units was processed and piped to the waste water treatment unit to neutralise the alkaline water.

The non-feed costs were estimated as $263,300,000 while the raw material costs were $30,043,420. The annual operating costs for plant with CO_2 integration is $293,343,420.

4.7 Cash flow analysis

The cash flow model was developed based on the following cost models:

*Revenue = Price per barrel * Number of barrels of GTL produced per year* (7)

*Taxes = Tax rate * (Revenue – Opex – Depreciation)* (8)

Net Cash Flow = Revenue – Capex – Opex – Taxes + Depreciation (9)

$$NPV(project) = A_0 + \sum_{t=1}^{n} \frac{F_t}{(1+k+p_t)^t} \tag{10}$$

Tables 3 and 4 respectively show the discounted cash flows generated from the GTL project without and with carbon dioxide capture at 10% discount rate using Equations 7 to 10. From Tables 3 and 4, the NPV of the project without carbon capture at 10% discount rate is $1,766.32 Million while the cumulative cash flow was $129,898.50 Million while for the plant with CO_2 recovery the NPV was $2529.92 and the cumulative cashflow was $163,382.16.

5. Results and discussion

The NPV and payback period for the two options were compared in this work. The cash flow model incorporating the various discount rates, tax schemes, CAPEX, OPEX, depreciation and revenue were setup for the two options considered in this work using Microsoft Excel as shown in Tables 3 and 4. From Tables 3 and 4, at 10% discount rate, the NPV was $1766.32 Million and $2529.92 Million for plant without and plant with CO_2 capture for wastewater treatment respectively. The cumulative cashflow for the whole project life was $129,898.50 Million for the plant without CO_2 recovery, while the plant with CO_2 recovery had a cumulative cash flow of $163,382.16 Million. The graph of payback period in Figure 5 showed that the plant without CO_2 recovery had a payback period of 4.6 years whilst for plant with CO_2 recovery it was 3.7 years.

Table 3. Cash flow at 10% discount rate of GTL plant without CO_2 recovery

Year	Annual Revenue ($)	Capex ($)	Opex ($)	Depre ($/yr)	Tax ($)	Net Cash flow ($)	Inf.Rate (%)	Dis. Factor	NPV ($)	Cumu.Cash flow ($)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00000	0.00	0.00
1	0.00	1900.00	0.00	0.00	0.00	-1900.00	0.00	0.90909	-1727.27	-1900.00
2	1437.52		334.04	68.00	641.70	529.78	0.03	0.78315	414.89	-1370.22
3	1437.52		334.04	68.00	641.70	529.78	0.03	0.69305	367.16	-840.45
4	1437.52		334.04	68.00	641.70	529.78	0.03	0.61332	324.92	-310.67
5	1437.52		334.04	68.00	641.70	529.78	0.03	0.54276	287.54	219.11
6	1437.52		334.04	68.00	641.70	529.78	0.031	0.47778	253.11	748.88
7	1480.65		344.06	70.04	659.41	547.22	0.031	0.42244	231.16	1296.10
8	1480.65		344.06	70.04	659.41	547.22	0.031	0.37351	204.39	1843.32
9	1480.65		344.06	70.04	659.41	547.22	0.031	0.33025	180.72	2390.53
10	1480.65		344.06	70.04	659.41	547.22	0.031	0.29199	159.78	2937.75
11	1480.65		344.06	70.04	659.41	547.22	0.032	0.25568	139.91	3484.96
12	1525.07		354.38	72.14	677.65	565.18	0.032	0.22586	127.65	4050.14
13	1525.07		354.38	72.14	677.65	565.18	0.032	0.19952	112.77	4615.32
14	1525.07		354.38	72.14	677.65	565.18	0.032	0.17626	99.62	5180.49
15	1525.07		354.38	72.14	677.65	565.18	0.032	0.15571	88.00	5745.67
16	1525.07		354.38	72.14	677.65	565.18	0.033	0.13562	76.65	6310.85
17	1570.82		365.01	74.31	696.44	583.69	0.033	0.11970	69.87	6894.53
18	1570.82		365.01	74.31	696.44	583.69	0.033	0.10565	61.67	7478.22
19	1570.82		365.01	74.31	696.44	583.69	0.033	0.09325	54.43	8061.90
20	1570.82		365.01	74.31	696.44	583.69	0.033	0.08230	48.04	8645.59
21	1570.82		365.01	74.31	696.44	583.69	0.034	0.07131	41.62	9229.27
22	1617.94		375.96	76.53	715.79	602.72	0.034	0.06288	37.90	9832.00
23	1617.94		375.96	76.53	715.79	602.72	0.034	0.05545	33.42	10434.72
24	1617.94		375.96	76.53	715.79	602.72	0.034	0.04890	29.47	11037.44
25	1617.94		375.96	76.53	715.79	602.72	0.034	0.04312	25.99	11640.17
26	1617.94		375.96	76.53	715.79	602.72	0.034	0.03802	22.92	12242.89
Total	**38160.00**					**12242.89**			**1766.32**	**129898.50**

Table 4. Cash flow at 10% discount rate of GTL plant with CO_2 recovery

Year	Annual Revenue ($)	Capex ($)	Opex ($)	Depre ($/yr)	Tax ($)	Net Cash flow ($)	Inf.Rate (%)	Dis. Factor	NPV ($)	Cumu.Cash flow ($)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00000	0.00	0.00
1	0.00	1645.60	0.00	0.00	0.00	-1645.60	0.00	0.90909	-1496.00	-1645.60
2	1437.52		293.34	65.82	608.86	611.32	0.03	0.78315	478.75	-1034.28
3	1437.52		293.34	65.82	608.86	611.32	0.03	0.69305	423.67	-422.97
4	1437.52		293.34	65.82	608.86	611.32	0.03	0.61332	374.93	188.35
5	1437.52		293.34	65.82	608.86	611.32	0.03	0.54276	331.80	799.67
6	1437.52		293.34	65.82	608.86	611.32	0.03	0.48032	293.63	1410.99
7	1480.65		302.14	67.79	627.13	629.66	0.031	0.42244	265.99	2040.65
8	1480.65		302.14	67.79	627.13	629.66	0.031	0.37351	235.18	2670.30
9	1480.65		302.14	67.79	627.13	629.66	0.031	0.33025	207.94	3299.96
10	1480.65		302.14	67.79	627.13	629.66	0.031	0.29199	183.86	3929.62
11	1480.65		302.14	67.79	627.13	629.66	0.031	0.25817	162.56	4559.28
12	1525.07		311.20	69.83	645.95	648.55	0.032	0.22586	146.48	5207.83
13	1525.07		311.20	69.83	645.95	648.55	0.032	0.19952	129.40	5856.39
14	1525.07		311.20	69.83	645.95	648.55	0.032	0.17626	114.31	6504.94
15	1525.07		311.20	69.83	645.95	648.55	0.032	0.15571	100.98	7153.49
16	1525.07		311.20	69.83	645.95	648.55	0.032	0.13755	89.21	7802.05
17	1570.82		320.54	71.92	665.32	668.01	0.033	0.11970	79.96	8470.06
18	1570.82		320.54	71.92	665.32	668.01	0.033	0.10565	70.57	9138.07
19	1570.82		320.54	71.92	665.32	668.01	0.033	0.09325	62.29	9806.07
20	1570.82		320.54	71.92	665.32	668.01	0.033	0.08230	54.98	10474.08
21	1570.82		320.54	71.92	665.32	668.01	0.033	0.07264	48.52	11142.09
22	1617.94		330.16	74.08	685.28	688.04	0.034	0.06288	43.26	11830.14
23	1617.94		330.16	74.08	685.28	688.04	0.034	0.05545	38.15	12518.18
24	1617.94		330.16	74.08	685.28	688.04	0.034	0.04890	33.64	13206.22
25	1617.94		330.16	74.08	685.28	688.04	0.034	0.04312	29.67	13894.26
26	1617.94		330.16	74.08	685.28	688.04	0.034	0.03802	26.16	14582.31
Total	**38160.00**					**14582.31**			**2529.92**	**163382.16**

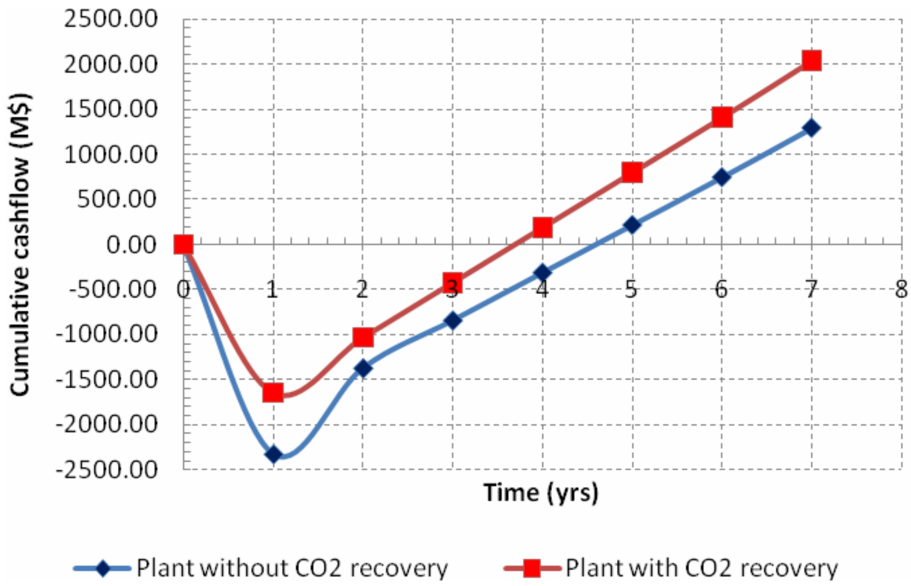

Figure 5. Pay back periods of the two GTL plant options

5.1 Effects of increase in plant size

The plant sizes of two plants (one existing and another proposed) were considered in this analysis. An existing 12,500 bbl/day GTL plant and the proposed 140,000 bbl/day GTL plant were used in this study. The cost for GTL plant size of 34,000 bbl per day was used as a standard reference. The corresponding costs for the 12,500 bbl/day and 140,000 bbl/day were determined. The economic parameters outlined above in this study were applied to the two plants. The plot of the cumulative cash flow against time is shown in Figure 6. The plant capacity of 140,000 bbl/day has a payback period of 2.85 years while the 12,500 bbl/day has a payback of 6.60 years.

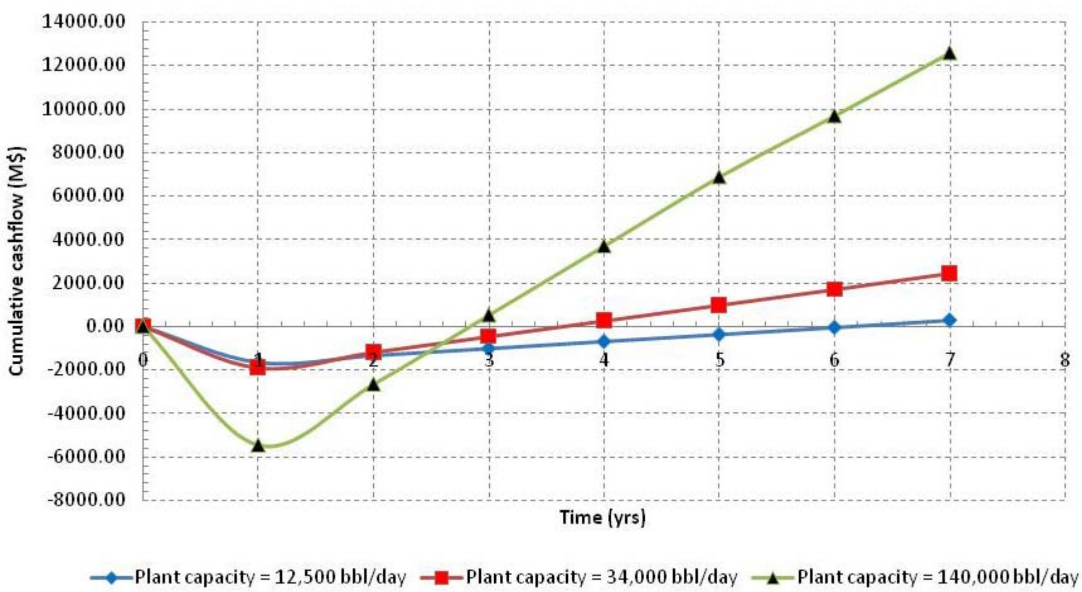

Figure 6. Payback periods for different plant capacities

5.2 Risk analysis and economic implications

Sensitivity analyses were performed to evaluate the effects of changing various economic factors that influence the economic viability of wastewater treatment using CO_2. Variables that were analysed include changes in (1) total investment level (2) generated revenue and (3) inflation rate. In the analyses, one variable at a time was changed and its impact on the NPV of the wastewater neutralisation was determined.

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5.3 Monte Carlo simulation

Monte Carlo simulation technique was used to analyse the effects of varying the inputs (assumptions) on the output of the economic model. Risk analysis software "Crystal Ball (CB)" was used to run a Monte Carlo simulation. It requires the definition of two types of cells in the Microsoft Excel spreadsheet as shown in Tables 3 and 4. The cells that contain variables or parameters are defined as assumption cells while the cells that contain outcomes of the model are called forecast cells. Each forecast cell contains a formula that is dependent on one or more of the assumption cells. The simulation calculates multiple scenarios of the model by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell.

The first step in running the simulation was to identify all the assumptions by identifying the inputs that are estimates or are subject to change over time. For each uncertain variable, the possible value with a probability distribution is defined. The type of distribution selected is based on the conditions that surround that variable.

The next step was to identify the forecast cell. A forecast cell is a cell containing formula that is to be evaluated. For this work the NPV and Cumulative Cashflow were selected as the forecast cells while the revenue, CAPEX, inflation rate were the assumption cells.

For this work, the NPV was selected as the forecast cells and the triangular distribution was chosen as the probability distribution option. The simulations used in this work were based on 5000 iterations in each case.

When a simulation is run for 5000 trials, 5000 forecasts are created, compared to the single outcome obtained in the deterministic spreadsheet. For the economic model used, the results of 5000 trials of NPV were obtained and displayed in interactive histograms or frequency charts as shown in Figures 7 and 8 for the GTL plant without and with wastewater neutralisation using CO_2 respectively.

The frequency charts give an insight analysis of the economics of wastewater treatment techniques in GTL plant using CO_2 or mineral acid by presenting the certainty range for each forecast. The histogram in Figure 7 shows that there is a 95% certainty level that at 10% discount rate, NPV of the plant without CO_2 neutralisation option will lie between \$2198.52 Million and \$3367.25 Million with the mean value of \$2753.22 Million.

Similarly Figure 8 shows that at the same 10% discount, there is 95% certainty level that, the NPV of the plant with CO_2 neutralisation option will lie between \$2525.26 Million and \$3711.01 Million with a mean value of \$3126.86 Million. The statistics show that both the mean outcomes from the simulation are positive for the two options. However the option with CO_2 neutralisation had a higher mean value and hence is economically better than the option without CO_2 neutralisation.

The values represented in the sensitivity charts in Figures 7 and 8 were measured by Rank correlation. The horizontal bars in these sensitivity charts represent the overall effect on the project economics by the parameters obtained from each of the labeled distribution assumptions respectively. In the same way, the percentage contribution of each parameter to the uncertainties surrounding the forecast or outcomes is labeled on each horizontal bar.

The bars extending to the left hand side of the 0.0% trend line represent negative correlation coefficients while any parameter whose bar extends to the right of the 0.0% tread line has positive correlation coefficients. It can be seen that the annual revenue has the greatest effects on the NPV forecast while the CAPEX and inflation rate have negative coefficients. An increase in this negative coefficient will translate to a decrease in the cash flow which will cause a resultant decrease in the NPV and longer payback.

The corresponding sensitivity charts show that generated revenue has over 85% influence on net earnings of GTL plant.

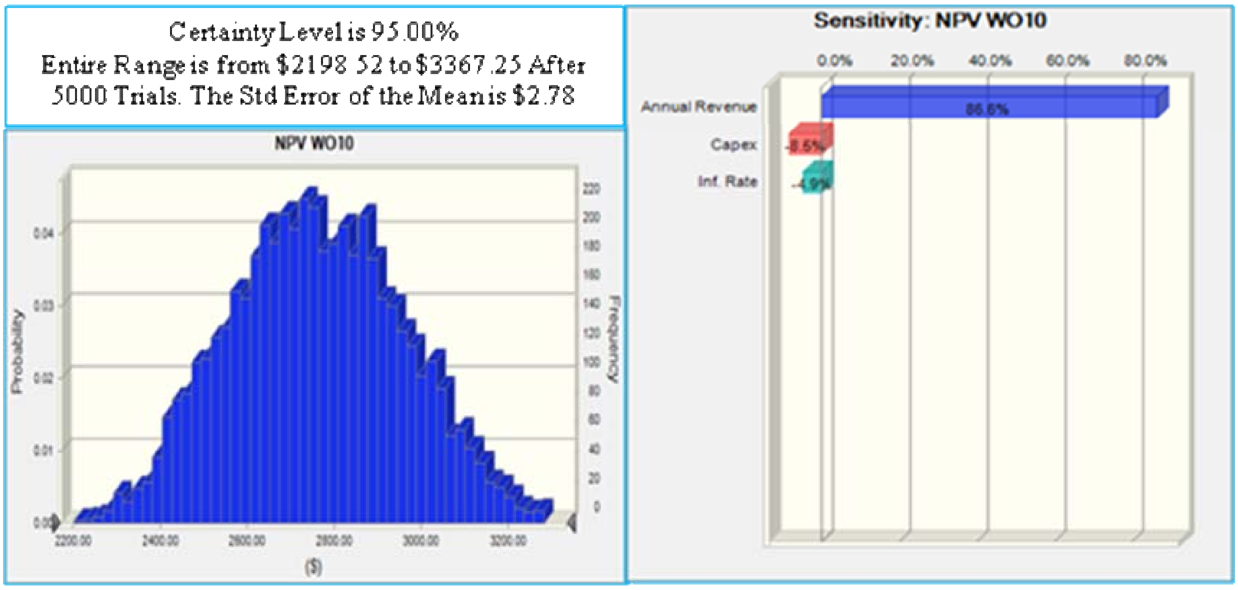

Figure 7. NPV and sensitivity chart at 10% forecast for plant without CO_2 recovery

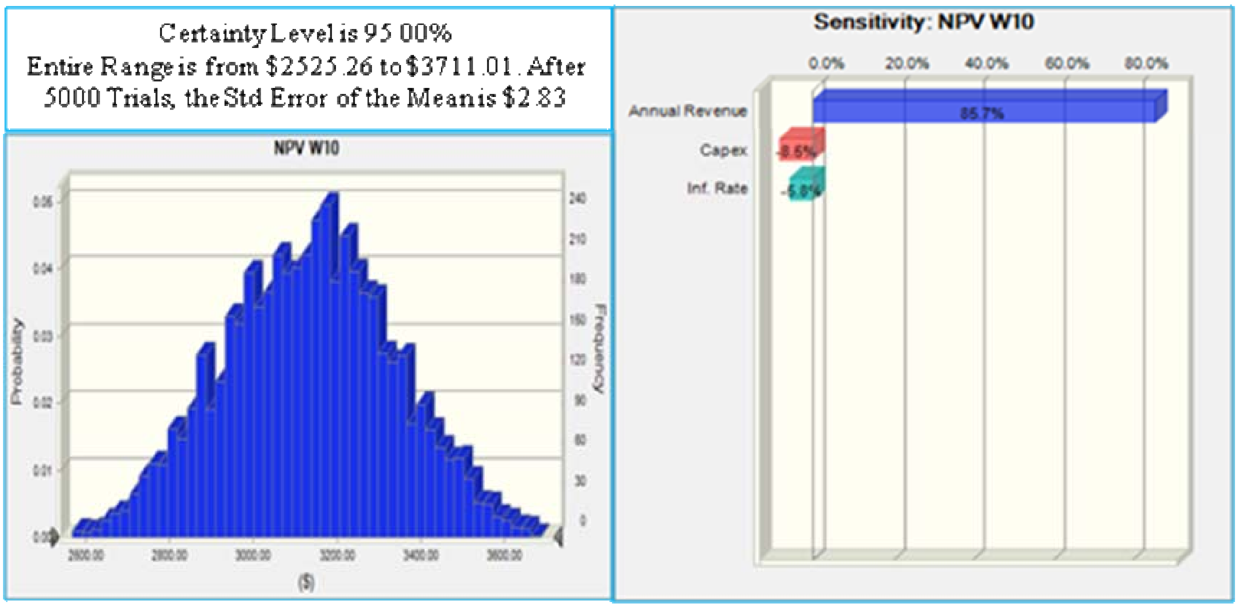

Figure 8. NPV and sensitivity chart at 10% forecast for plant with CO_2 recovery

6. Conclusion

The economics of the proposed wastewater neutralisation option using CO_2 was studied and compared with the current method of wastewater treatment in a GTL plant. The payback period of the proposed option was 3.7 years compared to the 4.6 years for the conventional method. The cumulative cash flow of the proposed method at 10% discount rate was $33,483.66 more than the conventional method. The economic parameters used in this study, showed that the proposed method is economically and environmentally better than the current method used in the industry.

The economy of scale also gave an indication that the higher the plant capacity, the better the return on investment. The simulated results using Monte Carlo simulation and the sensitivity analysis confirms that wastewater treatment using CO_2 has 95% certainty level that the NPV of the plant with CO_2 neutralisation option has a mean value of $3126.86 Million compared to that of conventional method which has a mean value of $2753.22. The results also show that the generated revenue has over 85% influence on the net earnings of the project.

It could be concluded economically that the proposed plant option with CO_2 recovery for wastewater neutralisation will be profitable to build or retrofit than the present option where sulphuric acid is used in wastewater treatment.

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