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# Design Parameters Affecting the Commercial Post Combustion $CO_2$ Capture Plants

Ahmed Aboudheir* and Walid Elmoudir

HTC Purenergy Inc.
002 - 2305 Victoria Ave. Regina, Saskatchewan, S4P 0S7 Canada

**Abstract**

A comprehensive design exercise for a 4,500 TPD $CO_2$ capture plant is conducted based on coal flue gas streams at three recovery rates ranging between 80% and 90%. Three solvents (30wt% MEA, HTC formulated solvents RS-2™ and RS-1210) and enhanced configurations are utilized to achieve the production capacity at minimum emission to atmosphere and minimum energy consumptions. Design parameters and performance comparison of different scenarios are presented in terms of flue gas rates, solvent circulation rates, cooling duties, steam consumption, electricity consumption, main equipment sizes, and emissions to atmosphere.



*keywords: large-scale $CO_2$ capture plant, rate based modelling, coal fired power plant*

## 1. Introduction

The post-combustion carbon dioxide ($CO_2$) capture from gaseous mixtures by means of liquid absorbents is a proven technology and will continue to be one of the leading industrial techniques for many decades to come. There are several existing commercial $CO_2$ capture plants from coal flue gas using conventional configurations and monoethanolamine (MEA) solvent. The production capacity of these existing plants ranges from 130 to 800 tonne per day (TPD) and $CO_2$ is used for food and chemical industry applications. To improve the efficiency and the productivity of this existing and proven technology, it is important to use enhanced process configurations and formulated solvents in order to

* Corresponding author: T: +1-306-352-6132; F: +1-306-545-3262
Email address: aaboudheir@htcenergy.com


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meet larger production capacity and to meet the environmental requirements at minimum utility consumptions. In this paper, a comprehensive design for a 4,500 TPD $CO_2$ capture plant is conducted based on a coal flue gas at 3 recovery rates ranging between 80% and 90%. The HTC formulated solvent and enhanced configurations are utilized to achieve the production capacity at minimum emissions to atmosphere, minimum utility requirements, and minimum capital/operating costs. The rate based modelling, which involves the use of actual chemical kinetics, thermodynamic properties, heat transfer, and mass transfer of multi-component systems and employ the real column configuration and internals, is used to design and optimize this plant. Rate based approach, for absorption/stripping process simulation is recommended for complex and non-ideal systems such as amine treatment plants [1–3]. All the design parameters are based on pilot plant scale up methodology. Performance comparison in terms of tables/figures between these different solvents and $CO_2$ recovery rates are presented in terms of flue gas rate, solvent circulation rate, cooling duty, steam consumption, power consumption, and main equipment sizes.

## 2. Model Validation

The formulated model to design the commercial plant is extensively validated against actual performance data from pilot plants and existing commercial plants as shown in Table 1. The main performance parameters considered in these comparisons are: the production capacity, solvent circulation rate, rich loading, rich solvent concentration, steam consumptions, temperatures of the main streams, flow rate of main streams, and composition of main streams.

As can be seen from Table 1, the predicted performance results were found to be in close agreement with the measured values in all the above performance parameters. Based on these agreements between the predicted and measured performance data, it can be concluded that no significant challenges and risks should be expected in designing, building, and operating large-scale amine based plants that are similar to the plant designed in this paper.

Table 1 Pilot Plants and Commercial Plants Data versus the Rate Based Model Predictions

| | Plant Name | Production Capacity | Solvent | Plant Configuration | Average Absolute Deviation, % |
|---|---|---|---|---|---|
| Pilot Plants | ERTF | 1 TPD | MEA | TKO™ | 12.2% |
| | | | RS-2™ | | 10.6% |
| | Boundary Dam | 4 TPD | MEA | TKO™ | < 10% |
| | | | RS-2™ | | |
| Commercial Plants | AES | 130 TPD | MEA | Standard | 8.0% |
| | SVM | 800 TPD | MEA | Standard | 6.7% |

## 3. Plant Design

The coal fired power plants produce flue gases, which contain high levels of $CO_2$ and other impurities such as SOx, NOx, and fly ash. The flue gas should be pre-treated to reduce SOx, NOx, and fly ash levels prior introducing them to the amine based process for $CO_2$ capture. These pre-treatments are outside the scope of work of this paper and it has been assumed that the flue gas has been treated to meet the requirement of the amine process. For example, the level of $SO_2$ is recommended to be less than 10 ppmv in order to minimize the solvent loss due to solvent degradation [4]. Table 2 shows the flue gas condition and composition that has been used in the plant design of this work. As shown in the Table 2, the plant is designed to handle three different $CO_2$ recovery rate and accordingly, the flue gas feed flow rate could be varied as required.

Table 2 Flue gas composition and condition

| **Temperature, °C** | 60.55 | |
|---|---|---|
| **Pressure, bar** | 1.00 | |
| **Flow rate, kg/sec** | 357 | 80% $CO_2$ recovery Case |
| | 336 | 85% $CO_2$ recovery Case |
| | 317 | 90% $CO_2$ recovery Case |
| **Water, mol%** | 21.138 | |
| **$CO_2$, mol%** | 11.597 | |
| **$N_2$, mol%** | 61.434 | |
| **$O_2$, mol%** | 5.815 | |

The rate based model has been utilized to optimize the process configuration in order to minimize the capital cost and the operating cost while meeting the required clean-up targets and production capacity. The flue gas rate can be handled in one train consisting of three major sections: direct contact cooler (DCC), absorption column, and stripper column. DCC is mainly required to condition and cool the flue gas temperature before entering to the absorber section. The DCC will produce excess water from water condensation during the cooling process, which can be used for water make-up after filtration process to remove any fly ash or solid fine particles. In our current process configuration, this excess water from DCC is sent to the top of the washing section as a water make-up and to wash/cool the off-gas in order to reduce the solvent loss considerably (> 98%) and to maintain the plant in water balance. The reflux water is directed to the bottom of the absorber. This will have some benefits on the overall energy utilization and the capital/operation cost reduction.

Figure 1 shows the HTC overall process flow diagram recommended for the large scale $CO_2$ capture plants. The results from the plant modelling are presented in Table 3 for the HTC formulated Solvent, RS-1210, which will be used to demonstrate the main design key factors. The packed material selected for this system is M350X structure packing. The optimum absorber packed bed height and diameter have been found to be 8.5 m and 15 m, respectively, using this solvent. The absorber bed height for RS-1210 is higher than MEA by 25-30% but lower than RS-2 by 35-40%. The solvent circulation rate is 540 kg/sec at $CO_2$ recovery rate of 80% and with minor increase in the other two $CO_2$ recovery rates of 85% and 90%. The required reboiler energy in terms of saturated steam at 140 °C is about 1.46 kg steam per kg $CO_2$ captured at 80% $CO_2$ recovery rate.

## 4. Comparison of HTC Formulated Solvents Performance versus 30 wt% MEA

The first important process parameter is the solvent circulation rate, which will affect mainly the equipment size. As illustrated in Figure 2, the 30 wt% MEA solvent would require higher solvent circulation rate than the two HTC formulated solvents RS-2 and RS-1210 by roughly 9% and 18%, respectively. Less circulation flow rate of formulated solvents means smaller equipment size (i.e. columns, heat exchangers and pumps) comparing to 30 wt% MEA plant, which will lead to less capital costs.

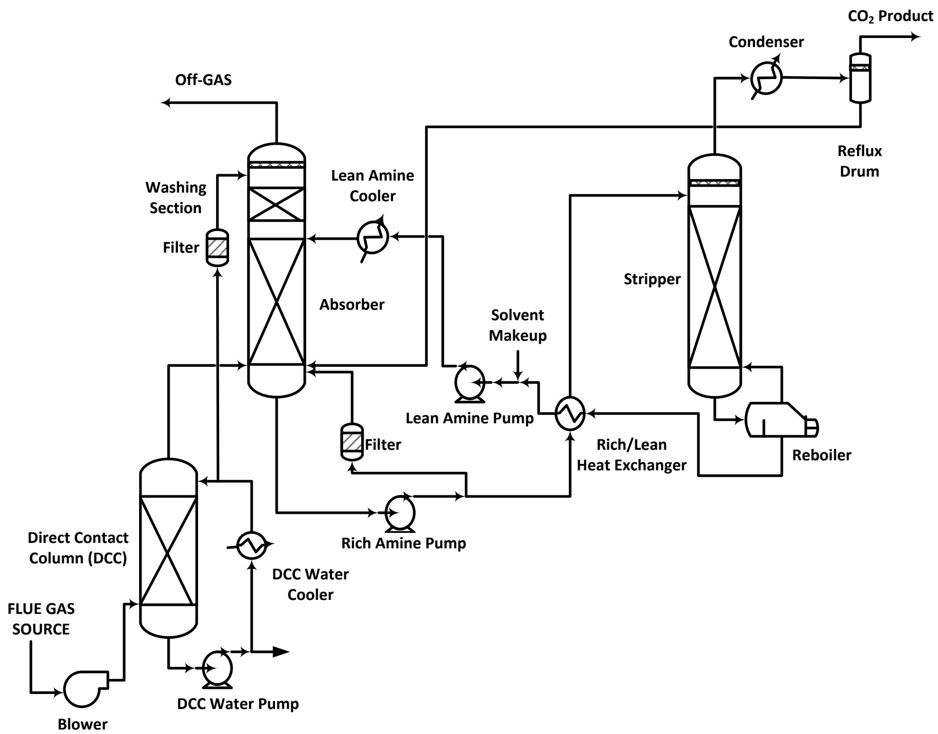


Figure 1 HTC Process Flow Diagram for Large Scale $CO_2$ Capture Plants

Table 3 HTC Formulated Solvent RS-1210™ Design Scenarios

| | | | | | |
|---|---|---|---|---|---|
| Solvent Type | | - | RS-1210 | | |
| $CO_2$ Production | | TPD | 4502.22 | 4512.50 | 4511.55 |
| $CO_2$ Recovery | | % | 80.02 | 85.22 | 90.22 |
| Amine Circulation Rate | | kg/sec | 540 | 545 | 550 |
| Absorber | Operating Temperature | °C | 40-60 | | |
| | Operating Pressure | bar | 1 | | |
| | Diameter/ Bed Height | m / m | 15 / 8.5 | | |
| Wash Section | Bed Height | m | 1 | | |
| Stripper | Operating Temperature | °C | 110-125 | | |
| | Operating Pressure | bar | 2 | | |
| | Diameter/ Bed Height | m / m | 9.5 / 8 | | |
| Energy | Reboiler Duty | MW | 162.85 | 164.70 | 168.50 |
| | Steam | kg/(kg $CO_2$) | 1.46 | 1.47 | 1.50 |
| Total Cooling Duty Demand | | MW | 152.89 | 155.42 | 159.50 |
| Total Power Consumption | | kW | 793.51 | 795.98 | 802.32 |

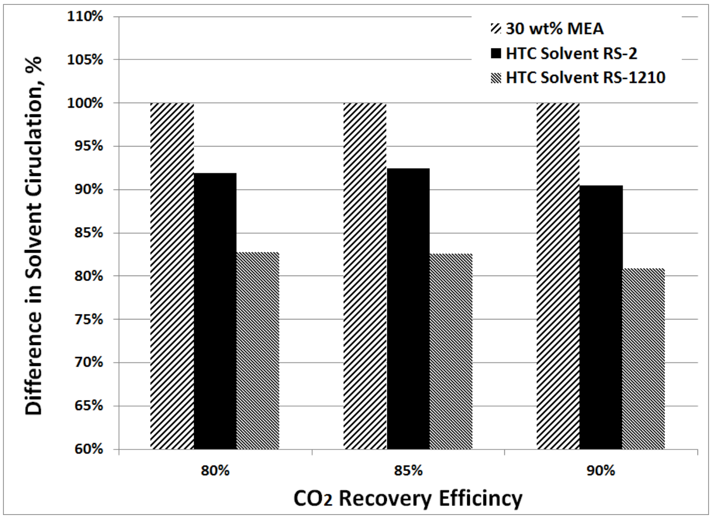


Figure 2 Solvent Circulation Rate of HTC Formulated Solvents versus 30 wt% MEA

The second most important parameter is the energy consumption for the solvent regeneration. The heating medium could be steam, heating oil, or direct fired heater depending on the plant location and energy sources availability. Figure 3 clearly shows that the steam requirement in the case of 30 wt% MEA is higher than that for HTC formulated solvents RS-2 and RS-1210. The difference is 15% for RS-2 solvent, while it is about 9-10% for RS-1210. The less energy consumption for the solvent regeneration means there would be less operating cost. If required, the energy consumption of the HTC formulated solvent can be reduced further by using more complex plant configuration on the expense of increasing the capital cost.

Table 4 represents the effect of the overall design approach on the operating and capital expenditures of the $CO_2$ capture plants. Without heat integration between the $CO_2$ plant and the adjacent industry, low operating and capital expenditures can be achieved on the expense of increasing the reboiler steam consumption slightly at less than 1.5 kg steam per kg $CO_2$. This steam consumption can be reduced further by heat integration if accessible onsite as shown for project B, which shows steam consumption of less than 1.0 kg steam per kg $CO_2$.

## 5. Conclusion

The findings of this design exercise show that the 4,500 TPD $CO_2$ capture from coal flue gas power plant is feasible and that the production capacities and the clean-up targets can be easily achieved at minimum $CO_2$ production cost using formulated solvent, advanced but simplified process configuration, and optimum operating conditions.

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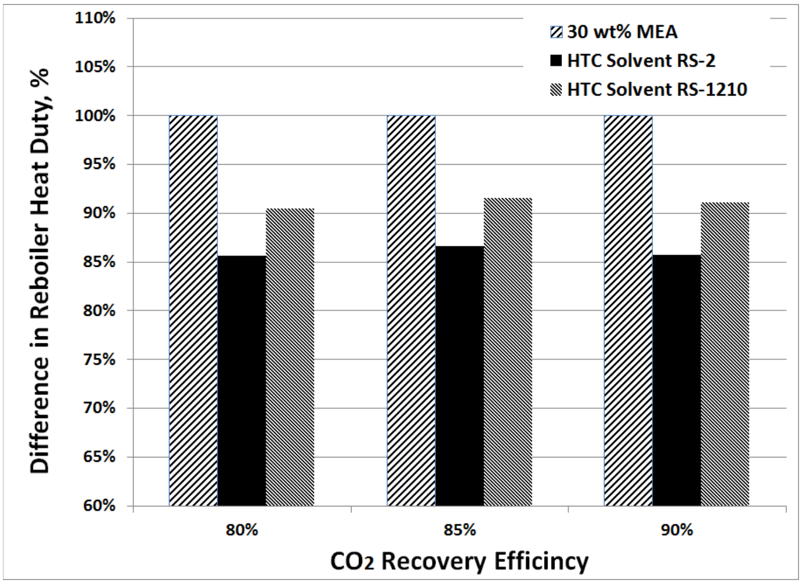


Figure 3 Regeneration Energy of HTC Formulated Solvents versus 30 wt% MEA

Table 4: Effect of design approach on the operating and capital expenditure

| | This Design | Project A | Project B |
|---|---|---|---|
| Reboiler saturated steam, 140 °C, kg/kg $CO_2$ | < 1.5 | < 1.2 | < 1.0 |
| Formulated solvent | RS-1210™ | RS-2™ | RS-2™ |
| Heat Integration | No | No | Yes |
| Plant Configuration | Simple | Complex | Complex |
| Number of control loops | Low | High | High |
| Plant Operation | Simple | Complex | Complex |
| Number of Operators | Low | High | High |
| Solvent circulation rate | Low | High | High |
| Equipment Size | Small | Large | Large |
| Capital expenditure | Low | High | High |
| Operating Expenditure | Low | Low | Low |