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RSAT™ process development for post-combustion CO_2 capture: Scale-up from laboratory and pilot test data to commercial process design

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Abstract

It is believed that a RSAT™ (Regenerable Solvent Absorption Technology) process is the most viable near-term technology for post-combustion CO_2 capture from power plant flue gas. The Babcock & Wilcox Power Generation Group, Inc. (B&W) has deployed a suite of research tools to evaluate and develop the CO_2 scrubbing technology, including laboratory, pilot-scale, and simulation modeling capabilities. Since the construction and operation of test facilities require significant resources, it is essential to effectively utilize these research tools by choosing a scale-up approach which provides robust design data for a commercial process while minimizing the amount of experimentation required.

The scale-up protocol used for RSAT CO_2 scrubbing processes was rigorously developed using rate-based modeling concurrent with acquiring fundamental laboratory and pilot plant data for process validation. These development activities were not conducted in series but rather overlapped to yield an optimized commercial CO_2 scrubbing process in a reasonable time frame with a high degree of design confidence [1, 2].

This paper presents the scale-up protocol used in evaluating the RSAT process which encompasses both laboratory and pilot-scale testing as well as rate-based modeling to achieve a commercial-scale RSAT process design. This document demonstrates the qualification of test data from a packed tower scale-up point of view. Solvent screening research activities recently conducted within B&W successfully demonstrate the scale-up protocol used for RSAT process development. The time and cost of process development can be significantly reduced through rigorous rate-based modeling in conjunction with laboratory experiments and pilot plant validation.

Keywords: CO_2 Scrubbing, Wetted-Wall Column, Pilot Plant, Simulation, Packed Tower Scale-up.

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1. Introduction

Regenerable solvent chemical absorption is a complicated, non-ideal electrolyte aqueous solution separation process, which deals with multiple components in both gas and liquid phases. The mass transfer with chemical reaction in liquid phase is critical for the gas and liquid separation process. Conventional amine processes for CO_2 capture are capital intensive and have a high operating cost. It is our intent to evaluate better solvents, improve the process flow sheet, and reduce steam consumption for capturing CO_2 from power plant flue gas. Optimization requires a fundamental understanding of solvent properties, mass/heat transfer with chemical reaction, column and equipment performance, and development of rigorous rate-based process simulation/modeling tools. Quantifying the impacts of solvent thermodynamic properties and chemical reaction kinetics from laboratory experimentation, and understanding column internal performance impact on the RSAT CO_2 scrubbing process is not a straightforward path, but rather a time consuming effort in both the lab and pilot plant. B&W's RSAT scale-up protocol is the integration of several steps. First, evaluation of solvents takes place at lab-scale by identifying mass transfer rate and CO_2 cyclic capacity from a wetted-wall column and estimation of absorption heat based on data obtained from a wetted-wall column. Then potential solvents selected in the previous step are advanced to the bench-scale integrated RSAT Simulator. For promising solvents, rigorous detailed tests in the wetted-wall column and RSAT Simulator are required to provide fundamental data for building simulation models. The identified solvents with an established simulation rate-based model are advanced to pilot scale test for validation. With a simulation tool as support and guidance, only crucial process parameters need to be tested in the RSAT pilot without comprehensive parametric studies, which saves time and reduces the cost associated with running a full pilot test campaign for solvent evaluation purposes. Analysis and qualification of pilot test data are performed to validate the model and ensure reliable scale-up to commercial size.

2. Experimental apparatus and simulation tool

The wetted-wall column (WWC) is a differential gas-liquid contactor used to measure the kinetics and vapor-liquid equilibrium (VLE) under typical experimental conditions. Figure 1 shows WWC schematic; the dimensions are listed in Table 1. A detailed description of the WWC, test procedure and conditions can be found elsewhere [3, 4]. Careful control of apparatus temperature and pressure, concentration, and CO_2 solvent loading permit the generation of high-quality fundamental data, such as the chemical reaction rate constant, VLE data (P^*_{CO2}), the estimation of heat of absorption, overall mass transfer coefficient K_G, and liquid side mass transfer kg' coefficient [3, 4]. The general equation used to describe the absorption rate (N), or flux of CO_2 is listed in Equation 1.

$$N = (P_{CO2} - P^*_{CO2})K_G \qquad (1)$$

Kinetics of a specific solvent is represented by the liquid film mass transfer coefficient k_g' and can be extracted by applying Equation 2.

$$\frac{1}{K_G} = \frac{1}{k_g} + \frac{1}{k_g'} \qquad (2)$$

Where K_G can be obtained from analysis of the data from the WWC, and k_g, the gas film mass transfer coefficient, predicted by the correlation, which was experimentally determined with a good accuracy for this specific WWC and reported elsewhere [3, 4].

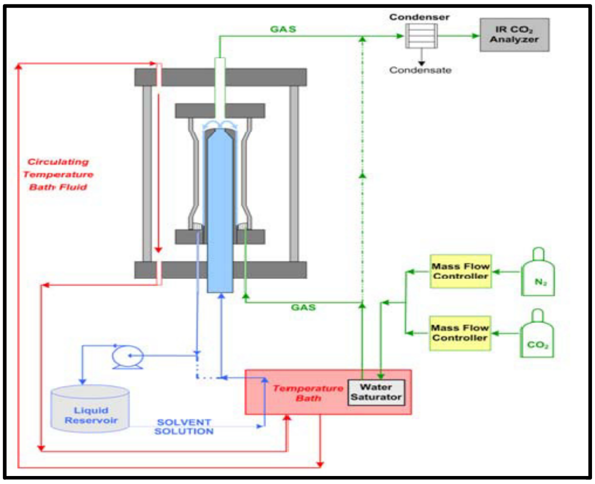

Figure 1. WWC Schematic

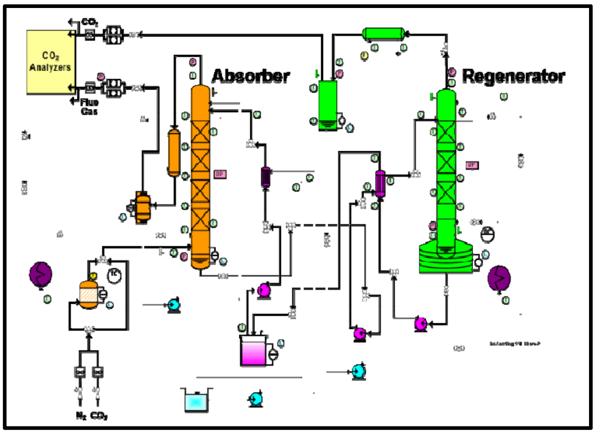

Figure 2. Schematic of RSAT™ Simulator

The **RSAT Simulator** is a fully-integrated bench-scale RSAT process testing facility. Figure 2 shows the schematic of this unit. The main dimensions of the RSAT Simulator are listed in Table 1. This testing facility provides the first opportunity to study an entire recycle process at small scale. The RSAT Simulator is flexible enough to easily be manipulated into different configurations, such as integrated versus absorber or regenerator separately. The columns can be packed with different type, size and height of packing. This small size makes its construction and testing inexpensive compared to pilot plants. The RSAT Simulator is used in solvent evaluation, parametric studies of operating conditions, and packing characterization since it includes see-through glass columns. Furthermore, this facility can be run long enough to allow for impurities to accumulate such as degradation products, which is an important criterion to select a potential solvent.

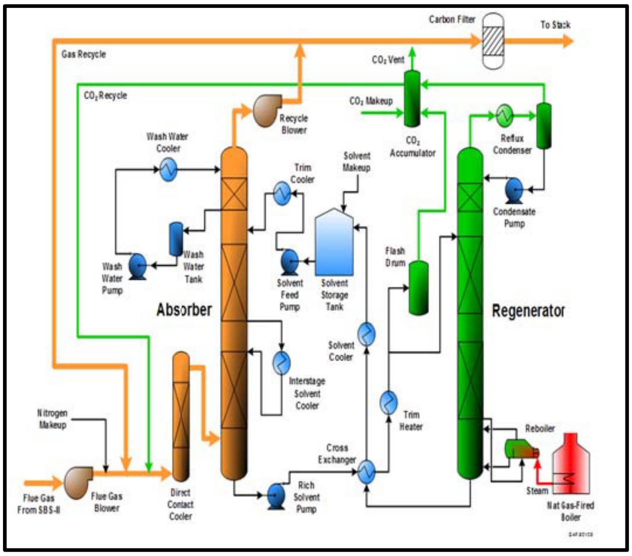

Figure 3. Schematic of RSAT Pilot Plant

The **RSAT Pilot Plant** is a completely integrated CO_2 scrubbing system with 7 tonne/day capture capacity. The main dimensions of the RSAT Pilot Plant are listed in Table 1. Figure 3 shows the schematic. This facility design provides operating flexibility along with the selective use of supplementary equipment for potential process improvements. The gas path has two possible operating modes: synthetic recycle and once-through flue gas. A coal flue gas slip stream from the adjacent Small Boiler Simulator II (SBS II) combustion unit allows for a typical power plant application scenario. Synthetic recycle gas functionality, comprised of N_2 and CO_2, is exclusively for research purposes to operate without interference from contaminants. Modular column construction affords versatility for changing internals and packing characterization studies. Both the absorber and regenerator columns have an overhead water wash section. Additional advanced process flow sheets include inter-stage cooling (intercooling), trim heaters, coolers, and flash tanks. The facility is well instrumented with a sophisticated data acquisition system. Commissioning started in the middle of 2009 and was conducted with 20wt% MEA. Baseline tests were performed with 30wt% MEA and accomplished by the end of 2009. Several solvent candidates were successfully tested in the current year to evaluate promising performance previously identified through laboratory experiments and provide test data for validation of rate-based models.

The **Rate-based simulation/modeling** was developed and implemented within ASPEN Plus® RateSep™ block and ProTreat™ as the main simulation platforms for newly identified and common solvents, respectively. Semi-empirical rate-based models were also developed in Microsoft Excel® for interpreting WWC test data, relative comparison of CO_2 removal efficiency, and estimation of reboiler heat duty for solvent evaluation [5].

A traditional equilibrium model can be validated against bench scale test facilities to determine various thermodynamic and reaction kinetics parameters. The ideal equilibrium separation stages were predicted by the validated model with accurate thermodynamic and reaction kinetics prediction. The ideal equilibrium stages combined with the estimated industrial packing efficiency (HETP - Height Equivalent Theoretical Plate), and column capacity data (liquid hold-up and pressure drop) provided by packing vendors were used for a final process and column design. Unlike a traditional equilibrium model, an accurate rigorous rate-based mathematical model is capable of predicting the actual performance of the real process over a wide range of operating conditions. In principal, the rate-based model predicts column performance without the need for estimation of packing efficiency (HETP). The rate-based model also describes thermodynamics and reaction kinetics of solvents, and simulates equipment efficiency and capacity by the predictive sub-models. Some of the sub-models, semi-empirical correlations for predicting mass/heat transfer, effective interfacial area, liquid hold-up, and column pressure drop require extensive industrial pilot scale data validation under a variety of operating conditions. Literature review indicates that the predictions of efficiency and capacity of packed column are inconsistent with different models which heavily depend on contacting column internals and system operating conditions [6, 7]. Test data from facilities such as the RSAT Simulator and similar miniature pilot plant configurations are not good enough for validation of the rate-based model. A large pilot plant with scale-up ready features will be necessary instead. The analysis of B&W pilot test facilities on column internal type, size, packing height, column diameter, test process operating conditions of gas and liquid flow rate, liquid hold up, and packing bed pressure drop is a very important first step to ensure the qualification of pilot test data, which can then be applied into the validation of rate-based models.

3. Scale up considerations of packed tower

Despite the significant advantages offered by structured packing on efficiency and capacity with high surface area and low pressure drop, design data in this field was limited for a specific solvent in the RSAT process. The physical properties of amine solutions are significantly different from many commonly used experimental fluids such as alcohols, air/water, and hydrocarbons in research facilities and by packing vendors. To provide the best possible scale-up data, and to understand and remove the technical risks associated with the design and operation of a larger industrial CO_2 scrubbing unit, test facilities must be built to represent the system involved. In addition, test operating conditions such as gas and liquid flow rate must be chosen within a good performance range of design load, which will vary with packing size and types. The following scale-up qualification analysis of B&W RSAT pilot testing was developed to ensure and obtain a reliable validation and design data from a pilot scale to a commercial process design. Table 1 shows the main dimensions of various research tools, typical operating conditions, and design parameters such as gas capacity factor, and liquid loads.

Kister [8] discussed in detail the criteria that should be met by a distillation test unit which will result in a successful scale-up of packing to a full size industrial unit. These criteria were applied to the CO_2 scrubbing process since this absorption/desorption system has similarities with the rectifying/stripping distillation process. For structured packing columns, packing type, gas/liquid distributor qualities and their installation methods have to be matched to those commercially practiced. Test conditions should be performed over the entire operating range.

Table 1: Dimensions, Typical Operating Conditions, Design Parameters

		Test Facilities					**Simulation Case**	
Parameters	**Units**	**WWC**	**Simulator**		**Pilot**		**500MWe**	
			Absorber	Regenerator	Absorber	Regenerator	Absorber	Regenerator
CO_2 capture rate	tonnes/day		0.02		7		1.0E+4	
Tower diameter	m	0.03	0.05	0.05	0.61	0.61	20	15
Packing bed height	m	0.09	1.28	0.91	7.6	7.6	16	10
Packing type		Single tube	Structured		Structured		Structured	
Surface area	m^2/m^3	45	954		350		250	
Element height	mm	91.3	55		267		210	
Crimp height	mm		3		8		12	
Gas flow rate, G	kg/hr	0.4	1.5		1410		2.45E+6	
Gas capacity factor	Pa$^{0.5}$	0.1	0.2		1.3		1.9	
Liquid flow rate, L	kg/hr	11	3 - 7.5		2820 - 8460		4.9E+6 - 1.5E+7	
Liquid load	m^3/m^2 hr	13	2 - 4		9 - 29		15 - 45	
Ratio mass flow, L/G	mass/mass	28	3 - 5		2 - 6		2 - 6	

Tower diameter: Recently, hydraulic scale-up research studies have shown that the pressure drop and capacity of a packed tower appear to be strongly dependent on diameter [6]. The study indicated that diameter should be two times larger than the packing element height to minimize adverse wall effects due to cross section reduction by wall wipers and increased number of bends in the vapor flow. Nominal element height of industrial structured packing is about 0.17 to 0.30 m, which indicates that tower diameter should be about 0.4 m or even larger. The B&W RSAT Pilot Plant unit absorber and regenerator columns have diameters of 0.61 m, meeting the two element rule. In addition, the ratio range of tower diameter to packing crimp height from 14 to 65 has proven sufficient to achieve reliable design data. The common structured packing installed at the B&W RSAT Pilot Plant exhibits a tower diameter to crimp height ratio of about 50 to 75. It is clear that pilot test data of this column size can be used with reliable distribution techniques without any scale-up factor to properly design commercial absorption and desorption columns.

In the case of the RSAT Simulator, the diameter is less than twice the packing element height, and the ratio range of tower diameter to packing crimp height is at the far end of the minimum requirement. A considerable portion of liquid runs along the column wall due to a high void space between the bed and the edge of the wall. Flow channeling was observed in the RSAT Simulator columns provided by its see-through feature.

Tower packing height: The packed column efficiency is determined not only by solvent physical properties, VLE, reaction kinetics, packing geometry, and operating conditions of liquid to gas mass flow ratio (L/G), but also CO_2 removal rate range. In other words, efficiency is determined by the slope of the vapor equilibrium curve, slope of the operating curve, and CO_2 removal rate requirement. The packing separation efficiency will be different in the case of 60% CO_2 removal rate as opposed to 90%. The total packing height must be designed high enough to meet the targeted CO_2 removal requirement. This is because the RSAT CO_2 scrubbing system exhibits a non-ideal, non-linear relation between removal rate and packing height. The range of removal rate also determines packing efficiency and in consequence, the packing height and type have to be representative to the industry standards. Since the RSAT Pilot Plant was designed with modular construction, the packing height can be changed as required and the total packing height enables a 90% CO_2 removal rate as the typical operating condition. Under these circumstances, the data obtained from the RSAT Pilot Plant can be directly used for scale-up of a commercial unit. Once the total height requirement is met, the quantity and height of each bed must be considered from a quality of liquid distribution point of view in which each packing bed height is neither too short nor too tall. Short beds, considered less than 1.5 m, tend to have lower packing efficiency as a result of end effects. End effects are defined by mass transfer in the region of liquid introduction and where liquid drips from the packing support. The packing bed should not be taller than 8 to 9 m to avoid liquid mal-distribution. For these reasons, packing beds between 3 to 6 m are well suited for scale-up. The RSAT pilot was designed with two bed sections of 4 m each with good liquid distribution between the packing beds. This arrangement ensured high quality data when conducting the scale-up effort.

Operation conditions: Test conditions, especially gas and liquid flow rate, will affect the data representation of the scale-up process. The gas flow rate should be operated near, but not at the flood point to find the best column performance. At the flooding point column separation efficiency is dramatically decreased. For an underperforming absorber column, the test data may not correctly represent commercial applications which usually are designed to be 70 ~ 80% or higher of the flood point, or 90% of the maximum capacity factor. Pilot test conditions, previously described in Table 1, are operated conservatively far from pre-flood points; the column efficiency is smaller compared to commercial packing design which is close to flood points. Therefore, commercial column diameter was sized to have a higher vapor load (higher gas capacity factor) and higher liquid load even with the same L/G as in a pilot plant. For these reasons, current RSAT pilot test data provide more safety design factor in commercial column designs.

Gas and liquid distribution: Liquid distribution quality is also investigated for the RSAT pilot plant regarding drip point density and layout, as well as the liquid distributor position compared with the industrial standard for the specified packing in the column. The distribution quality effect is adjusted in the simulation on interfacial area calculation. Meanwhile, vapor distribution does not impose a big issue in small diameter columns. The installation of a properly designed liquid collector at the bottom of the column, following industrial standards ensure uniformly gas distribution. This will need to be re-examined in a large commercial column.

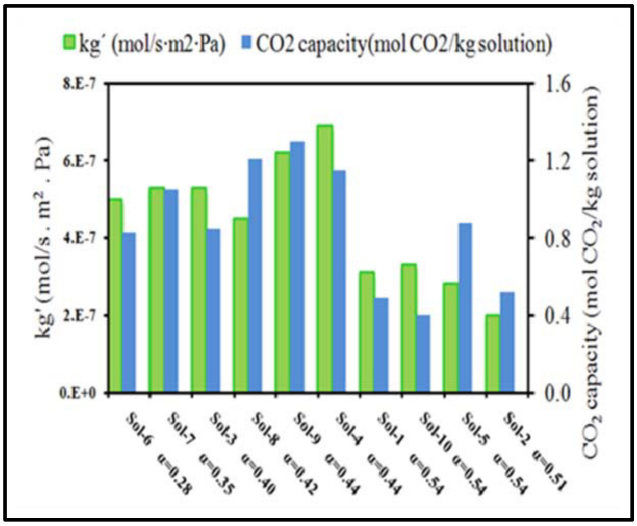

Figure 4. WWC Solvent Evaluation Results

WWC data scale-up: The WWC gas and liquid contacting channel was designed to resemble a real gas and liquid contacting channel between corrugated metal sheets of structured packing. Mass transfer data measured in the WWC either in gas or liquid phase can be approximated to the mass transfer data provided by structured packing. The 100 mm long metal tube and equivalent diameter of 30 mm is an analogous design to the typical geometry of structured packing. Common industrial structured packing has with 100 to 300 mm packing element height and 25 mm of corrugated width. Since WWC gas inlet conditions are different from actual packing beds, and measured/calculated k_g values are higher than real packing beds, the overall K_G mass transfer coefficient cannot be used for direct scale-up. In addition, k_g' mass transfer coefficient in the liquid phase is determined by reaction kinetics (k_g'') in the liquid film and the reaction and product diffusion term ($k_{g,fd}''$) in the liquid phase. k_g' is further defined as in Equation 3

$$\frac{1}{k_g'} = \frac{1}{k_g''} + \frac{1}{k_{g,fd}''} \tag{3}$$

k_g'' is only affected by chemical reaction rate, solvent VLE, and physical properties, but $k_{g,fd}''$ is not only determined by VLE and physical properties, but also depends on gas and liquid hydrodynamics properties and physical geometry of diffusion device. The liquid solvent flowing over the surface of the WWC tube is in laminar flow with no packing edge dispersion or liquid back mixing effects; back mixing effects ultimately occur and reduce the mass transfer efficiency in real packed towers. The difference hydrodynamic of gas and liquid in WWC and in real packed tower made $k_{g,fd}''$ term is different from real packing than in packed towers. Because reactive absorption mass transfer rate of identified solvents is relatively faster

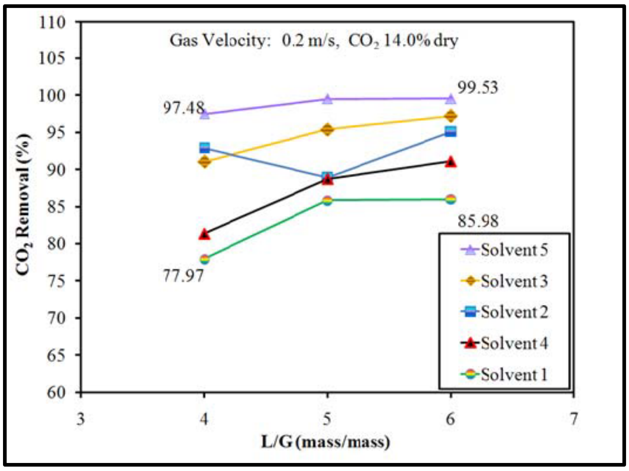

Figure 5. RSAT Simulator Solvent Evaluation

than 30wt% MEA, $k_g^{''}$ is so large, then the diffusion term $k_{g,fd}^{''}$ may be dominant in the real absorption process. Therefore, k_g' measured in WWC cannot be directly used in real absorber design.

The operating conditions of typical gas and liquid flow, L/G, gas capacity factor, and liquid load are also listed in Table 1. The WWC L/G is approximately 30 to 1, which is much higher than a real packed tower of nominal design less than 8. A higher L/G in the WWC ensures constant solvent concentration at the gas-liquid interface, which is hard to maintain under real operating conditions for commercial packed towers.

All of the above factors prevent directly using mass transfer coefficients K_G and k_g' obtained from the WWC for commercial packed towers design. However, it must be pointed out that the k_g' obtained can be used to compare relative solvent performance and $k_g^{''}$ extracted from WWC can be used to determine a chemical reaction constant used in rate-based models to calculate solvent properties from first principals.

4. Scale-up protocol application in solvent evaluation

WWC: The concentration of aqueous solvent solutions has been chosen based on extensive literature review along with laboratory and simulation studies. Liquid side mass transfer coefficient (k_g') data, describing the solvent reaction kinetics contribution to absorption rate, could be used to evaluate solvent kinetic performance relatively. This is because the most chemical absorption process studied is controlled by reaction kinetics in the liquid as opposed to diffusion controlled. Considering the kinetics and capacity information from all test campaigns, more than ten solvents were identified as promising candidates for further evaluation. Those solvents which have at least comparable kinetics and capacity potential to 30wt% MEA are represented in Figure 4. The CO_2 rich loading is reported on the x-axis of Figure 4 with an equilibrium partial pressure of CO_2 equal to 5000 Pa at 40°C.

RSAT Simulator: Figure 5 shows comparison of the promising solvents identified in the WWC and then tested in the RSAT Simulator. The x-axis of Figure 5 represents L/G, and the y-axis depicts CO_2 removal rate. The CO_2 removal rate was obtained at a fixed operation condition under the same reboiler heat duty for all tested solvents. The rank of solvents 1 to 5 exhibits a similar trend as the solvent performance obtained from WWC testing which can be seen in Figure 4. From Table 1, packing dimensions and process operation conditions such as L/G, packing type, and packing size are not a good representation of commercial industrial packed columns due to different gas and liquid hydrodynamic packing characterization. Even though the RSAT Simulator consisted of real packed columns, the packing was customized for bench-scale operation which introduced column size and height limitations. In consequence, it was not possible to directly scale-up test data from this facility to a commercial design level. However, the RSAT Simulator still represents a valuable tool to compare overall solvent performance. Solvents with high removal efficiency and less operational problems will be further tested at pilot-scale.

RSAT Pilot Plant: Due to the extensive time, effort and cost that it takes to implement test campaigns at large pilot-scale, solvents were evaluated in this facility only after they were investigated in the WWC, RSAT Simulator, and the modeling tools showed positive and promising performance. A flue gas flow rate of 1410 kg/hr was chosen from commissioning results for future solvent characterization tests based on packing bed hydrodynamic performance. Detailed parametric tests of process conditions, liquid flow rate and temperature, flue gas temperature and composition, regenerator reboiler heat duty, regenerator pressure, and reboiler steam rate were determined based on the 30wt% MEA baseline solvent. The major process operating conditions identified were L/G and reboiler steam rate. Detailed test matrices were assembled to determine the significance of operating parameters on each solvent. The optimization test matrix was chosen by varying L/G and identifying the steam supply required to achieve 90% removal. In consequence, a 90% CO_2 removal curve was developed for each solvent as indicated in Figure 6. The x-axis represents the L/G ratio and the y-axis shows the reboiler heat duty in terms of kJ/kg-CO_2.

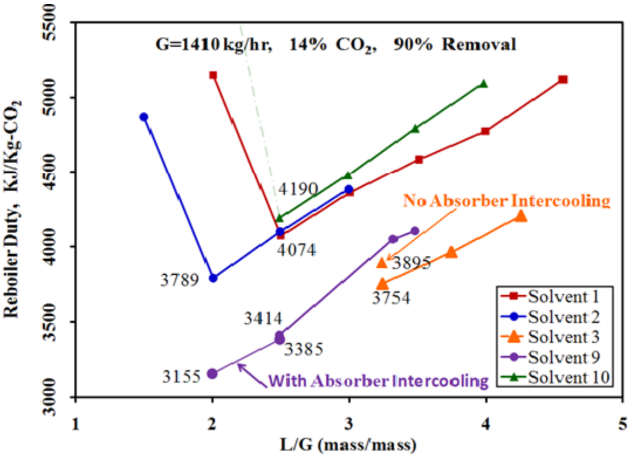

Figure 6. RSAT Pilot Plant Solvent Evaluation

Although reboiler steam requirement is a main focus, there are opportunities to leverage other process benefits to provide overall system enhancements. For example, higher regenerator pressures could lead to energy savings with respect to downstream sequestration activities. Considering individual solvent characteristics, test plans were designed to take advantage of beneficial solvent properties, such as intercooling effect under certain operating conditions. As indicated in Figure 6, absorber intercooling can further reduce reboiler heat duty given the particular condition. These parametric studies provide indication of how steam requirements can be further reduced for each solvent. When compared with the RSAT Simulator, the RSAT Pilot Plant provides high quality and quantitative data representative of industrial full-scale equipment and process configuration.

RSAT rate-based simulation validation: The rate-based models were validated against the tested solvents 1, 2, and 3 over a wide range of test conditions. For these tested solvents, Figure 7 shows the comparison of simulation cases in which reboiler heat duty is plotted by varying reboiler steam flow while maintaining other system process inputs constant to maintain a 90% CO_2 removal rate. Figure 7 clearly shows that the model predicts similar performance trends on each tested solvent. The reboiler heat duty (kJ/kg-CO_2) reported from the current pilot configuration was higher when compared with literature data for the known solvents. Data analysis indicated that higher reboiler heat duty was attributable to cross heat exchanger underperformance and low steam flow with respect to an over designed regenerator column diameter [10]. Based on the pilot scale-up analysis described herein, the current RSAT pilot plant structured packing (350Y) test data was directly scaled-up to a larger unit using similar size, geometry, and surface texture from the same vendor.

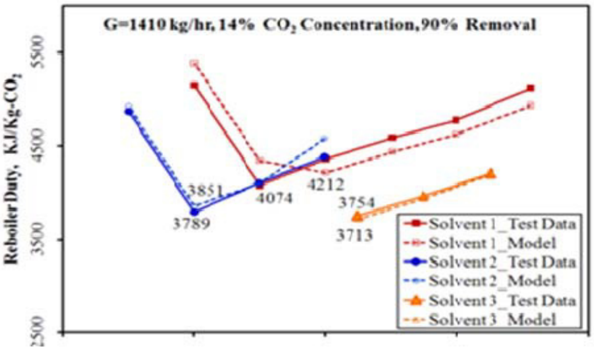

Figure 7. Pilot RSAT Rate-based Models Validation

500 MWe Commercial Plant Simulation Cases: The RSAT pilot is equipped with industrial type structured packing 350Y with 350 m^2/m^3 of surface area and a 45^0 corrugation angle. Based on the current selected solvent mass transfer efficiency and its capacity, size, geometry, and surface texture, 250Y (or X) is most likely to be used in a larger amine unit for CO_2 capture from power plant flue gas. Predictive sub-routines in rate-based models describing mass transfer coefficients in liquid and gas phase, liquid hold up, and interfacial contacting area are correlated with packing geometry effect of size and type. It is possible to scale up among different size of packing. In addition, scaling down from 350Y to 250Y packing has less risk than transitioning to another packing family due to the lower liquid distribution requirements for packing with less surface area. Therefore, the rate-based models were reliably scaled between 350Y (or X) and 250Y (or X) with minimal risk. Recent studies of corrugation angle effect on packing efficiency and capacity indicate that both packing types, 45^0 (Y) and 60^0 (X), exhibit similar performance, where X series may offer a larger capacity in CO_2 capture processes [9].The X series packing is expected to reduce column diameter with similar separation efficiency. It is also safe to scale-down from the current packing 350Y to 250Y under assumptions with equal or better gas/liquid distribution quality.

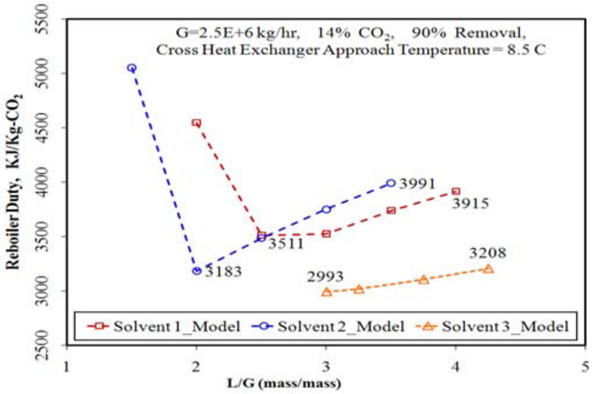

Figure 8. MWe 500 Rate-based Model Predictions

The rate-based models were validated with pilot data on a variety of solvent types and over a wide range of operating conditions, such as: pressure and temperature of inlet gas, temperature and solvent flow rate, different levels of CO_2 removal rate, absorber intercooling, cross heat exchanger approach temperature, and regenerator pressure effect. The validated models were scaled-up to a 500 MWe plant with a single train design assumption; the predicted tower diameters and packing bed heights are indicated in Table 1. Comparison of the reboiler heat duty results for each solvent is shown in Figure 8. The simulated reboiler heat duty is lower than the analogous results from the RSAT Pilot Plant at the same L/G. Moreover, the L/G with the minimum reboiler heat duty is consistent with the L/G identified by pilot plant tests for each solvent. The absolute reboiler heat duty (kJ/kg-CO_2) for the 500MWe commercial design is lower than the pilot plant findings under the same process operating conditions except for a smaller cross exchanger approach temperature and smaller size regenerator. Both an effective cross heat exchanger and an adequate regenerator design improve the CO_2 scrubbing efficiency.

The current rate-based models were only validated against fresh solvents without the consideration of long-term solvent degradation and corrosion. Degradation products reduce solvent capacity while corrosion reduces both packing capacity and efficiency from increased foaming tendencies. It is easier to achieve gas and liquid uniform distribution in a pilot-scale than in a larger size commercial plant. It was reported that 1% of the liquid channeling effect has resulted in an apparent loss of 44% of packing efficiency [11]. The gas and liquid distribution malfunction should be carefully considered in real commercial designs of 500 MWe power plants and above. The rate-based models are required for long-term validation against real flue gas conditions in order to evaluate solvent degradation and corrosion impact on solvent performance.

5. Conclusions

The scale-up protocol of structured packed towers with the combination of rate-based modeling, laboratory experimentation, and pilot-scale campaigns was applied to the CO_2 scrubbing process development. Rate-based modeling tools made the scale-up of packed towers direct and simple without using empirical HETP data for description of mass transfer efficiency. Rate-based modeling demands higher quality pilot data for validation. It was imperative to understand test facilities and test data in order to perform a relevant scale-up effort when conducting process development. Analysis of laboratory and pilot test facilities regarding column dimensions, packing internal type and size, and process operating conditions enhanced confidence in interpretation of test data into a commercial plant design. This analysis also indicated that current pilot test facilities provide data which meet the criteria of scale-up. The scale-up analysis ensured predictability and accuracy of validated rate-based models in the scaling of CO_2 scrubbing process design. Solvent screening recently conducted at B&W is an example of successfully utilizing scale-up protocol for RSAT process development. The time and cost of RSAT process development are significantly reduced through rigorous rate-based modeling in conjunction with laboratory and pilot plant experimental tests providing favorable results.

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