

# **A COMPARISON OF PHYSICAL SOLVENTS FOR ACID GAS REMOVAL**

Barry Burr and Lili Lyddon  
Bryan Research & Engineering, Inc.  
Bryan, Texas, U.S.A.

## **ABSTRACT**

Physical solvents such as DEPG (Selexol™ or Coastal AGR®), NMP or N-Methyl-2-Pyrrolidone (Purisol®), Methanol (Rectisol®), and Propylene Carbonate (Fluor Solvent™) are becoming increasingly popular as gas treating solvents, especially for coal gasification applications. Physical solvents tend to be favored over chemical solvents when the concentration of acid gases or other impurities is very high. In addition, physical solvents can usually be stripped of impurities by reducing the pressure without the addition of heat. This paper compares the acid gas removal ability, required equipment, and power requirements for the four physical solvents DEPG, Methanol, NMP, and Propylene Carbonate.

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## INTRODUCTION

Physical solvents such as DEPG (Selexol™ or Coastal AGR®), NMP or N-Methyl-2-Pyrrolidone (Purisol®), Methanol (Rectisol®), Propylene Carbonate (Fluor Solvent™), and others are becoming increasingly popular as gas treating solvents, especially for coal gasification applications. The process simulation program ProMax® [1] is used to perform comparisons for these physical solvents in terms of acid gas removal ability, equipment required, and power requirements. Before performing the final comparisons, the simulation results are verified by comparisons with experimental vapor-liquid equilibrium data.

## OPTIONS FOR ACID GAS REMOVAL

A number of methods are available for removal of acid gases from product gas streams. Some of the more commonly used methods are chemical solvents, physical solvents, membranes, and cryogenic fractionation [2]. Ethanolamines (MEA, DEA, MDEA, DGA, etc.) and hot potassium carbonate are chemical solvent processes which rely on chemical reactions to remove acid gas constituents from sour gas streams. The regeneration of chemical solvents is achieved by the application of heat whereas physical solvents can often be stripped of impurities by reducing the pressure without the application of heat. Physical solvents tend to be favored over chemical solvents when the concentration of acid gases or other impurities is very high. Unlike chemical solvents, physical solvents are non-corrosive, requiring only carbon steel construction.

In general, the economics of CO<sub>2</sub> recovery is strongly influenced by the partial pressure of CO<sub>2</sub> in the feed gas. At low partial pressures, physical solvents are impractical because the compression of the gas for physical absorption is expensive. However, if the gas is available at high pressure, physical solvents might be a better choice than chemical solvents.

The concentration of heavy hydrocarbons in the feed gas also affects the choice of gas treating solvent. If the concentration of heavy hydrocarbons is high, a physical solvent may not be the best option due to higher co-absorption of hydrocarbons, particularly pentanes plus. Unlike natural gases where hydrocarbon co-absorption can be a problem for physical solvents, synthesis gases do not contain appreciable quantities of hydrocarbons [3]. This makes physical solvents particularly applicable to synthesis gas treating.

The membrane process is applicable for high pressure gas containing high acid gas concentrations. CO<sub>2</sub> recovery is accomplished by pressure-driven mass transfer through a permeable membrane where separation is due to the differences in permeation rate of different compounds. The acid gas is recovered at low pressure. A high purity product containing approximately 95% CO<sub>2</sub> can be achieved with one or two stages, depending upon feed gas pressure and percent recovery. Economic considerations may dictate additional capital and incremental energy requirements to increase feed pressure and/or utilize two-stage separation with recompression of gas from the first stage.

Cryogenic fractionation has the advantage that the CO<sub>2</sub> can be obtained at relatively high pressure as opposed to the other methods of recovering CO<sub>2</sub>. This advantage may, however, be offset by the large refrigeration requirement. Special materials are also required for cryogenic service.

## COMMON PHYSICAL SOLVENTS FOR ACID GAS REMOVAL

A number of physical solvents are available for use in acid gas treating processes. A comprehensive list of common physical solvents may be found in *Gas Purification* [4]. Four of the solvents are considered here: Dimethyl Ether of Polyethylene Glycol (DEPG), Propylene Carbonate (PC), N-Methyl-2-Pyrrolidone (NMP), and Methanol (MeOH). An exhaustive literature survey reveals where and how these physical solvents are currently being used.

### **DEPG (Dimethyl Ether of Polyethylene Glycol)**

DEPG is a mixture of dimethyl ethers of polyethylene glycol ( $\text{CH}_3\text{O}(\text{C}_2\text{H}_4\text{O})_n\text{CH}_3$  (n is between 2 and 9) used to physically absorb  $\text{H}_2\text{S}$ ,  $\text{CO}_2$ , and mercaptans from gas streams. Solvents containing DEPG are licensed and/or manufactured by several companies including Coastal Chemical Company (as Coastal AGR), Dow (Selexol), and UOP (Selexol). Other process suppliers such as Clariant GmbH of Germany offer similar solvents. Clariant solvents are a family of dialkyl ethers of polyethylene glycol under the Genosorb<sup>®</sup> name [3].

DEPG can be used for selective  $\text{H}_2\text{S}$  removal which requires stripping, vacuum stripping, or a reboiler. The process can be configured to yield both a rich  $\text{H}_2\text{S}$  feed to the Claus unit as well as bulk  $\text{CO}_2$  removal. Selective  $\text{H}_2\text{S}$  removal with deep  $\text{CO}_2$  removal usually requires a two-stage process with two absorption and regeneration columns.  $\text{H}_2\text{S}$  is selectively removed in the first column by a lean solvent that has been thoroughly stripped with steam, while  $\text{CO}_2$  is removed in the second absorber. The second stage solvent can be regenerated with air or nitrogen for deep  $\text{CO}_2$  removal, or using a series of flashes if bulk  $\text{CO}_2$  removal is required. DEPG also dehydrates the gas and removes HCN.

Compared to the other solvents, DEPG has a higher viscosity which reduces mass transfer rates and tray efficiencies and increases packing or tray requirements, especially at reduced temperatures. Since it is sometimes necessary to reduce temperature to increase acid gas solubility and reduce circulation rate, this could be a disadvantage. DEPG requires no water wash to recover solvent due to very low vapor pressure. DEPG is suitable for operation at temperatures up to 347°F (175°C). The minimum operating temperature is usually 0°F (-18°C).

### **MeOH (Methanol)**

There are a number of Methanol processes for acid gas removal including the Rectisol process (licensed by Lurgi AG) and Ifpexol<sup>®</sup> (Prosernat). The Rectisol process was the earliest commercial process based on an organic physical solvent and is widely used for synthesis gas applications. The process operates at a very low temperature and is complex compared to other physical solvent processes. The main application for the Rectisol process is purification of synthesis gases derived from the gasification of heavy oil and coal rather than natural gas treating applications [4]. The two-stage Ifpexol process can be used for natural gas applications. Ifpex-1 removes condensable hydrocarbons and water, and Ifpex-2 removes acid gas [5].

Processing conditions and equipment are very different from the other solvents [6]. The Rectisol process is very flexible with many possible flow schemes. Product specifications and process objectives are the major factors in determining the optimum flow scheme. The Rectisol process can be configured to address the separation of synthesis gas into various components depending on the required final products.

Methanol has a relatively high vapor pressure at normal process conditions, so deep refrigeration or special recovery methods are required to prevent high solvent losses. Water washing of

effluent streams is often used to recover the Methanol. The Rectisol process typically operates below 32°F (0°C) and may be operated at temperatures as low as -95°F (-70.5°C). The process usually operates between -40°F and -80°F (-40°C and -62°C). Due to low temperatures, approximately 5% of the material in a Rectisol plant is stainless steel [3].

Methanol's high selectivity for H<sub>2</sub>S over CO<sub>2</sub> combined with the ability to remove COS is the primary advantage of the process [3]. Solubilities of H<sub>2</sub>S and COS in Methanol are higher than in DEPG. Rectisol's complex flow scheme and the need to refrigerate the solvent can be disadvantages with respect to higher capital and operating costs [3]. The supply of refrigeration at low temperatures requires much power. However, this disadvantage can be outweighed by a considerable reduction of the solvent flow rate for CO<sub>2</sub> removal as compared to other physical solvent processes [7]. Acid gas solubility in physical solvents increases significantly as the temperature decreases. Low temperature also reduces solvent losses by lowering the vapor pressure of the Methanol in the product streams. If H<sub>2</sub>S is to be removed from a gas with CO<sub>2</sub> remaining in the treated gas, Selexol and NMP are more suitable than Methanol [7].

### **NMP (N-Methyl-2-Pyrrolidone)**

The Purisol Process which uses NMP is licensed by Lurgi AG. The flow schemes used for this solvent are similar to those used for DEPG. The process can be operated either at ambient temperature or with refrigeration down to about 5°F (-15°C) [8].

NMP has a relatively high vapor pressure compared to DEPG or PC, and the licensor recommends water washing of both the treated gas and the rejected acid gases for solvent recovery [9]. Obviously, NMP cannot be used for simultaneous gas dehydration if a water wash is used. In general, NMP recovery with water is not necessary if the Purisol process is operated at subambient temperatures [8].

NMP has the highest selectivity of all the physical solvents considered here for H<sub>2</sub>S over CO<sub>2</sub>. COS is not as soluble as H<sub>2</sub>S, but it is hydrolyzed by the NMP solvent [8]. The Purisol process is particularly well suited to the purification of high-pressure, high CO<sub>2</sub> synthesis gas for gas turbine integrated gasification combined cycle (IGCC) systems because of the high selectivity for H<sub>2</sub>S. Extreme purity with regard to sulfur compounds is not normally required for such fuel gas, and carbon dioxide in the purified gas expands through the gas turbine to provide additional power [4].

### **PC (Propylene Carbonate)**

The Fluor Solvent process which uses PC is licensed by Fluor Daniel, Inc. and has been in use since the late 1950's [6]. PC is available as JEFFSOL<sup>®</sup> PC solvent [10] and is particularly advantageous in treating syngas.

PC has an advantage over the other solvents when little or no H<sub>2</sub>S is present and CO<sub>2</sub> removal is important. PC has lower solubilities of the gas being purified: light hydrocarbons in natural gas and hydrogen in synthesis gas [6]. This lower solubility results in lower recycle gas compression requirements for the gas flashed from the rich solvent at intermediate pressures, and lower hydrocarbon losses in the CO<sub>2</sub> vent gas stream.

Some recent improvements in Fluor Solvent process design include an intermediate pressure absorber to remove CO<sub>2</sub>. Addition of this absorber greatly reduces the volume of gas to be recompressed, thereby decreasing operating costs and product losses [11]. Another new process improvement involves feed chilling to reduce absorption of hydrocarbons [10]. Chilling the feed to 0°F (-18°C) condenses most of the hydrocarbons. For example, the C<sub>5</sub>+ content can be reduced to less than 0.5 mol%. Chilling also increases the solvent's acid gas holding capacity. This results in a lower

overall solvent circulation rate and lower plant cost. PC can operate at lower temperatures without becoming too viscous for good mass transfer.

DEPG and NMP are more selective than PC for H<sub>2</sub>S removal from gases containing CO<sub>2</sub>. Furthermore, PC cannot be used for selective H<sub>2</sub>S treating because it is unstable at the high temperature required to completely strip H<sub>2</sub>S from the rich solvent (PC becomes unstable at 200°F or 93°C). PC would probably not be recommended if H<sub>2</sub>S is present in more than trace concentrations since the low concentration of H<sub>2</sub>S permitted in treated gas means H<sub>2</sub>S removal is controlling [6]. Selexol and NMP are more suitable for selective H<sub>2</sub>S removal. The FLUOR Solvent Process should be used for treating feed gases containing low levels of H<sub>2</sub>S, typically less than 20 ppmv, when there is a 4 ppmv H<sub>2</sub>S sales gas requirement [10]. However, improved stripping allows treatment to 4 ppmv for gases containing up to 200 ppmv H<sub>2</sub>S. This new improvement in stripping uses 125 psia (medium pressure) flash gas as the stripping medium in a vacuum stripper [10]. It should be noted that hydrocarbon or hydrogen losses increase as the amount of stripping gas increases.

Propylene Carbonate has a higher vapor pressure than DEPG, however, solvent losses are low. PC requires no water wash to recover the solvent due to its low vapor pressure. PC is not completely soluble in water as are the other three physical solvents. Furthermore, PC reacts slowly but irreversibly with water and CO<sub>2</sub> around 194°F (90°C) making it unsuitable for water control by atmospheric distillation [8]. Glycol injection upstream of the absorber is used for hydrate control in feed chilling [10]. The operating temperature for PC is limited to greater than 0°F (-18°C) and a maximum operating temperature of 149°F (65°C).

### Comparison of Physical Solvent Properties and Gas Solubilities

The physical solvents considered here are non-corrosive, relatively non-toxic, and require only carbon steel construction. The selection of a physical solvent process depends on process objectives and characteristics of the solvents [6]. Some of those characteristics include selectivity for H<sub>2</sub>S, COS, HCN, etc., effect of water content in the feed gas, concurrent hydrocarbon absorption with acid gas removal, solvent cost, solvent supply, royalty cost, and thermal stability. The following table compares selected physical properties for the four physical solvents [7].

Table 1 – Properties of Physical Solvents

Solvent	DEPG	PC	NMP	MeOH
Process Name	Selexol or Coastal AGR	Fluor Solvent	Purisol	Rectisol
Viscosity at 25°C (cP)	5.8	3.0	1.65	0.6
Specific Gravity at 25°C (kg/m <sup>3</sup> )	1030	1195	1027	785
Molecular Weight	280	102	99	32
Vapor Pressure at 25°C (mmHg)	0.00073	0.085	0.40	125
Freezing Point (°C)	-28	-48	-24	-92
Boiling Point at 760 mm Hg (°C)	275	240	202	65
Thermal Conductivity (Btu/hr*ft*°F)	0.11	0.12	0.095	0.122
Maximum Operating Temperature (°C)	175	65	-	-
Specific Heat 25°C	0.49	0.339	0.40	0.566
CO <sub>2</sub> Solubility (ft <sup>3</sup> /U.S. gal) at 25°C	0.485	0.455	0.477	0.425

All of these physical solvents are more selective for acid gas than for the main constituent of the gas (e.g. hydrogen, carbon monoxide, methane, etc.). Relative solubilities of various gases in solvents relative to carbon dioxide at 25°C are presented in the following table [7,12]. Due to the relatively high volatility of Methanol, the solubilities for Methanol in Table 2 are presented at -25°C.

Table 2 – Solubilities of Gases in Physical Solvents Relative to CO<sub>2</sub>

Gas Component	DEPG at 25°C	PC at 25°C	NMP at 25°C	MeOH at -25°C
Hydrogen	0.013	0.0078	0.0064	0.0054
Nitrogen	0.020	0.0084	-	0.012
Oxygen	-	0.026	0.035	0.020
Carbon Monoxide	0.028	0.021	0.021	0.020
Methane	0.066	0.038	0.072	0.051
Ethane	0.42	0.17	0.38	0.42
Ethylene	0.47	0.35	0.55	0.46
Carbon Dioxide	1.0	1.0	1.0	1.0
Propane	1.01	0.51	1.07	2.35
i-Butane	1.84	1.13	2.21	-
n-Butane	2.37	1.75	3.48	-
Carbonyl Sulfide	2.30	1.88	2.72	3.92
i-Pentane	4.47	3.50	-	-
Acetylene	4.47	2.87	7.37	3.33
Ammonia	4.80	-	-	23.2
n-Pentane	5.46	5.0	-	-
Hydrogen Sulfide	8.82	3.29	10.2	7.06
Nitrogen Dioxide (NO <sub>2</sub> )	-	17.1	-	-
n-Hexane	11.0	13.5	42.7	-
Methyl Mercaptan	22.4	27.2	34.0	-
n-Heptane	23.7	29.2	50.0	-
Carbon Disulfide	23.7	30.9	-	-
Cyclohexane	-	46.7	-	59.5
n-Octane	-	65.6	-	-
Ethyl Mercaptan	-	-	78.8	-
Sulfur Dioxide	92.1	68.6	-	-
Dimethyl Sulfide	-	-	91.9	-
Benzene	250	200	-	-
Decane	-	284	-	-
Thiophene (C <sub>4</sub> H <sub>4</sub> S)	540	-	-	-
Water	730	300	4000	-
Hydrogen Cyanide	1200	-	-	-

Minor gas impurities such as carbonyl sulfide, carbon disulfide, and mercaptans are quite soluble in most organic solvents. These compounds are removed to a large extent along with the acid gases. The solubility of hydrocarbons in organic solvents increases with the molecular weight of the hydrocarbon. Thus hydrocarbons above ethane are also removed to a large extent and flashed from the solvent along with the acid gas. Although special designs for the recovery of these compounds have been proposed, physical solvent processes are generally not economical for the treatment of hydrocarbon streams that contain a substantial amount of pentane-plus hydrocarbons. Unless a stripping column is used with a reboiler, the heavy hydrocarbons tend to accumulate in the solvent.

The solvent's capacity for absorbing acid gases increases as the temperature is decreased. A decrease in temperature can reduce the circulation rate, thus reducing operating costs. Also, the amount of light hydrocarbon or H<sub>2</sub> and CO may be reduced significantly. The solubility of CH<sub>4</sub>, H<sub>2</sub>, and CO show little change with temperature, so the absorption of acid gas is more selective.

### **Physical Solvent Regeneration**

The simplest version of a physical solvent process involves absorption followed by regeneration of the solvent by flashing to atmospheric pressure or vacuum, or by inert gas stripping. If H<sub>2</sub>S is present at only very low concentrations or is entirely absent, this flow scheme is usually applicable since CO<sub>2</sub> concentrations as high as 2 or 3% can often be tolerated in the product gas. When H<sub>2</sub>S is present in significant amounts, thermal regeneration is usually necessary to accomplish the thorough stripping of the solvent needed to reach stringent H<sub>2</sub>S purity requirements. As noted previously, PC cannot be thermally regenerated since it is unstable at the high temperature required to completely strip H<sub>2</sub>S from the rich solvent. Heat requirements are usually much less for physical solvents than for chemical solvents such as amines since the heat of desorption of the acid gas for the physical solvent is only a fraction of that for chemical solvents. The circulation rate of the physical solvent may also be less, particularly when the acid gas partial pressure is high.

## VERIFICATION OF SIMULATION RESULTS

Before the solvents can be compared via process simulation, the predicted solubilities of selected components in the solvents are compared with experimental vapor-liquid equilibrium data from Bucklin and Schendel (1984) [6] for DEPG, NMP, and Propylene Carbonate, and for Methanol using experimental vapor-liquid equilibrium data from Ranke and Mohr (1985) [7] and from Rousseau et al. (1981) [13].

Table 3 – Solubilities of Selected Gases in Physical Solvents vs. ProMax Predictions (1 atm and specified temperature in Volume Gas/Volume Solvent)

Component	DEPG at 25°C		NMP at 25°C		Propylene Carbonate 25°C		Methanol at -25°C	
	Data	ProMax 2.0 (SRK)	Data	ProMax 2.0 (P-R Polar)	Data	ProMax 2.0 (SRK)	Data	ProMax 2.0 (P-R Polar)
Carbon Dioxide	3.63	3.69	3.57	3.42	3.41	3.53	13.46	13.24
Hydrogen	0.047	0.018	0.020	0.023	0.027	0.025	0.073	0.069
Carbon Monoxide	0.10	0.062	0.075	0.067	0.072	0.079	0.269	0.135
Methane	0.24	0.23	0.26	0.25	0.13	0.29	0.686	0.727
Carbonyl Sulfide	8.46	12.2	9.73	10.19	6.41	15.1	52.75	56.76
Hydrogen Sulfide	32.4	37.0	36.4	30.94	11.2	14.51	147.0*	172.3*

\*Data at -25°C and 2 atm from Rousseau et al. (1981) [13]

### SOLVENT COMPARISON

The four solvents are compared using simulations performed with the process simulator ProMax<sup>®</sup> 2.0. Since physical solvent processes are commonly used for carbon dioxide removal from crude hydrogen and ammonia synthesis gases, this application has been selected for the comparison. Hydrocarbon losses are not considered here since the example uses a syngas which contains very little hydrocarbon.

Depending on the degree of contaminant removal, a wide variety of regeneration schemes are available. Flash regeneration using one or more flash steps which might include a final vacuum flash, inert gas stripping (nitrogen, fuel gas, or air when no sulfur species are present), thermal regeneration, or a combination of these methods may be utilized. In general, selective and non-selective configurations of these physical solvent processes may be used. For simplicity, the less complicated non-selective processes are compared in this study.

The feed gas composition is that of the basic non-selective Rectisol Wash example presented by Ranke [7] and listed in Table 4. The feed pressure is 464 psia and the temperature is 77°F with a flow rate of about 200 MMSCFD. The flow configuration and some of the process parameters for the Methanol case are also taken from the non-selective Rectisol Wash example. However, many of the parameters such as solvent flow rate are not given in the reference and were estimated. The flow rates and configurations for the other solvents were modified to achieve the treated gas composition obtained in the Methanol simulation (1.75 mole% CO<sub>2</sub> and less than 0.5 ppmv H<sub>2</sub>S + COS). For DEPG and NMP, both chilled and non-chilled cases are included for comparison with the chilled Methanol and PC cases.

Table 4 – Feed Gas Composition for Physical Solvent Comparison

Component	Mole %	Component	Mole %
Hydrogen	54.7	Methane	2.0
Nitrogen	0.2	Carbon Dioxide	42.2
Argon	0.4	Hydrogen Sulfide	0.05
Carbon Monoxide	0.4	Carbonyl Sulfide	0.05

### Flow Configurations

The flow configuration for the Methanol simulation is shown below. It is taken from the non-selective Rectisol wash example presented in Ranke and Mohr (1985) [7].

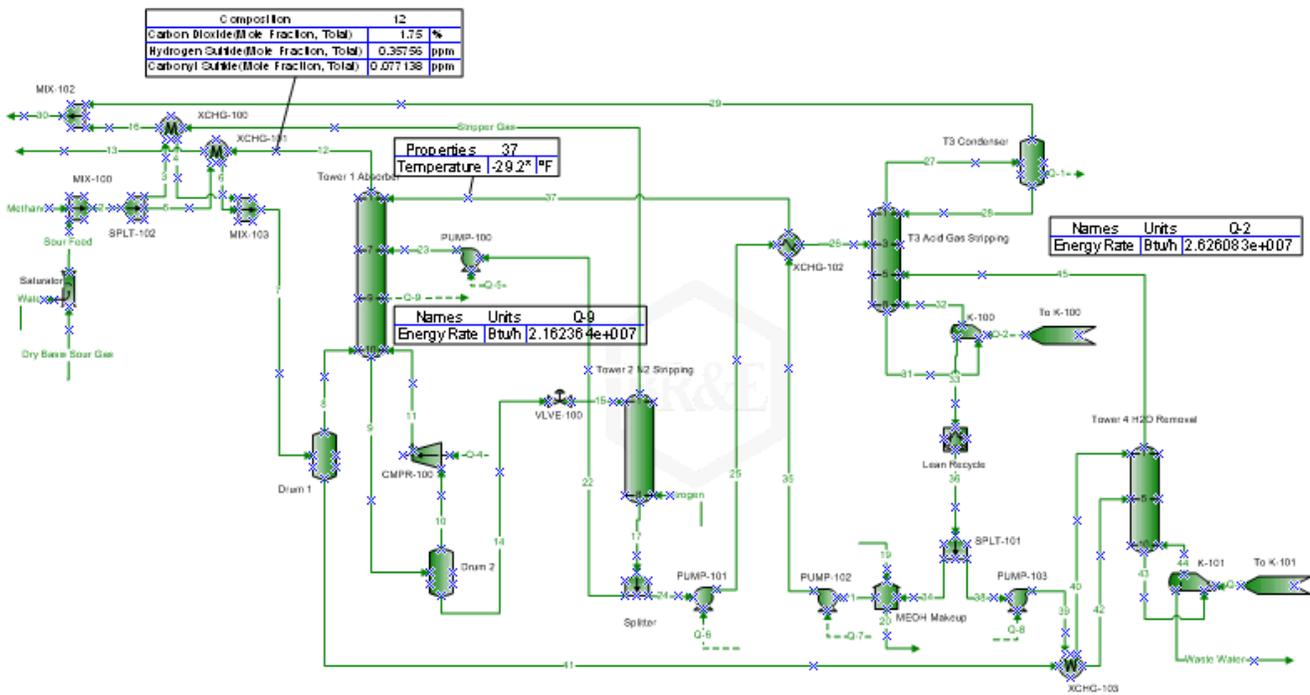


Figure 1 – Acid Gas Removal with Methanol

The flow configuration for the DEPG and NMP cases with no chilling are very similar. The DEPG flow configuration is shown in Figure 2.

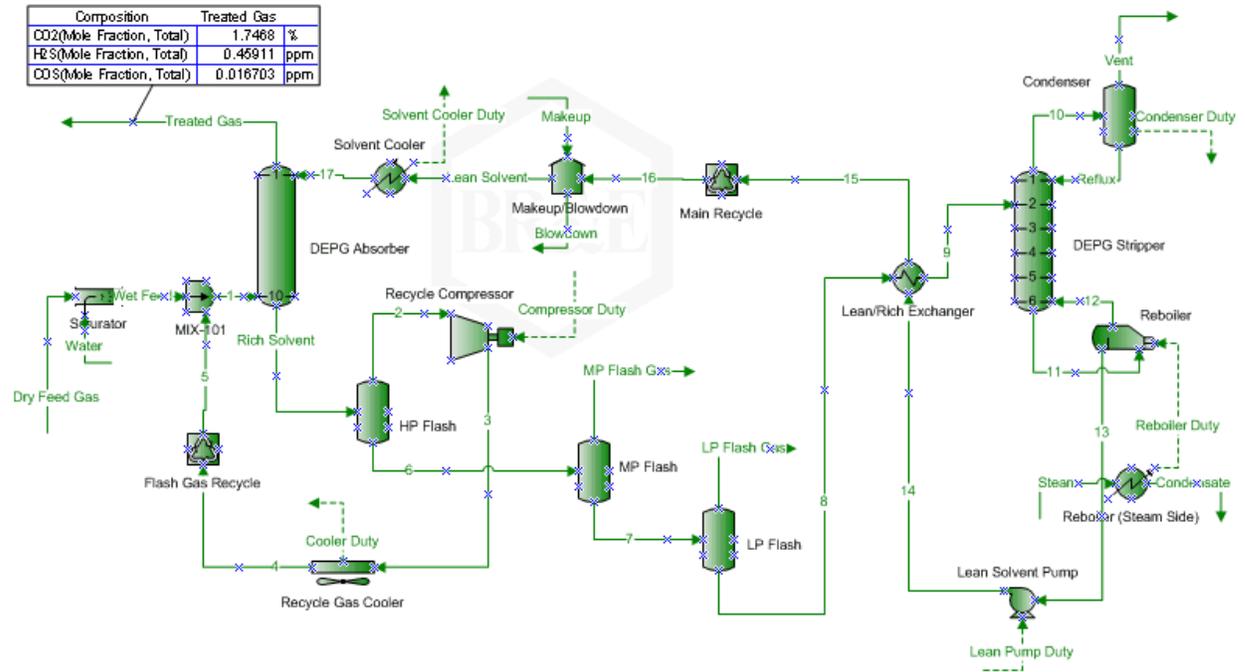


Figure 2 – Acid Gas Removal with DEPG

The flow configuration for chilled DEPG and NMP cases is the same. The NMP chilled solvent configuration is shown in Figure 3.

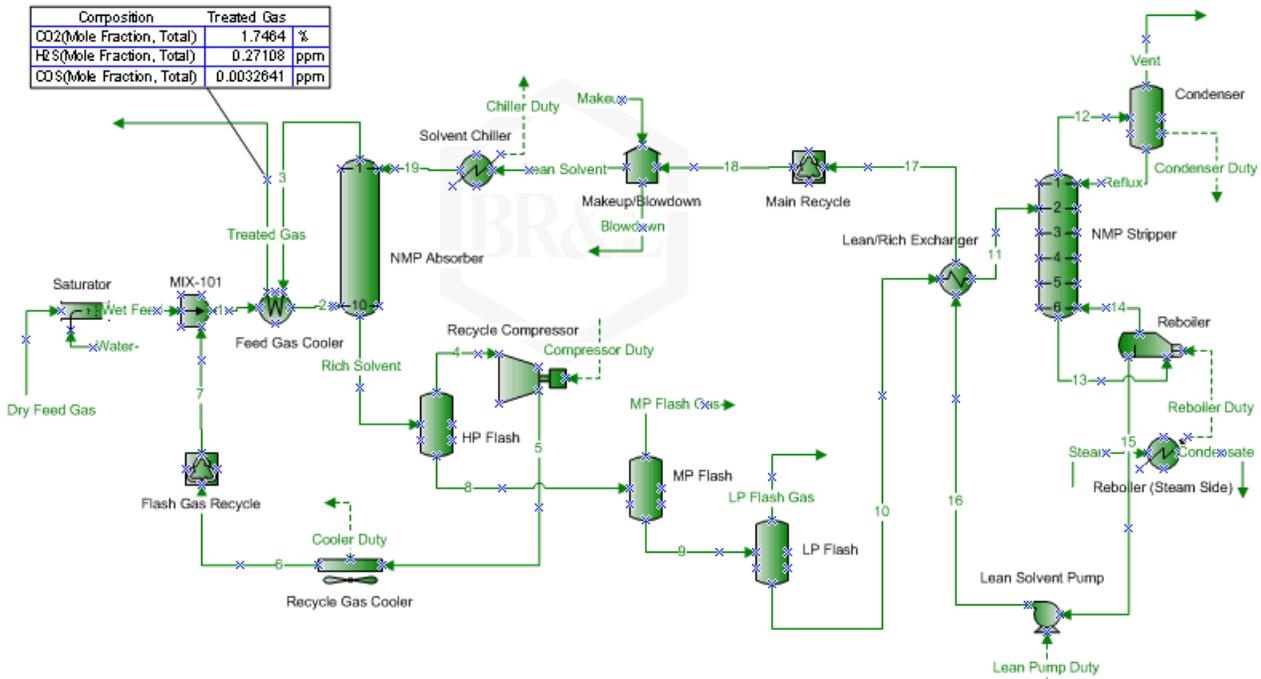


Figure 3 – Acid Gas Removal with Chilled NMP

For the PC case, the flow configuration is different from that of DEPG and NMP in the feed section. PC requires EG to be injected upstream of the feed gas cooler, and a chiller/separator is included to further chill the gas and separate the glycol from the chilled feed. Since the PC operating temperature cannot exceed 65°C, a 2 psia vacuum stripping column utilizing medium pressure flash gas as described by Mak and Nielsen [10] is used instead of the reboiler used for the other solvents.

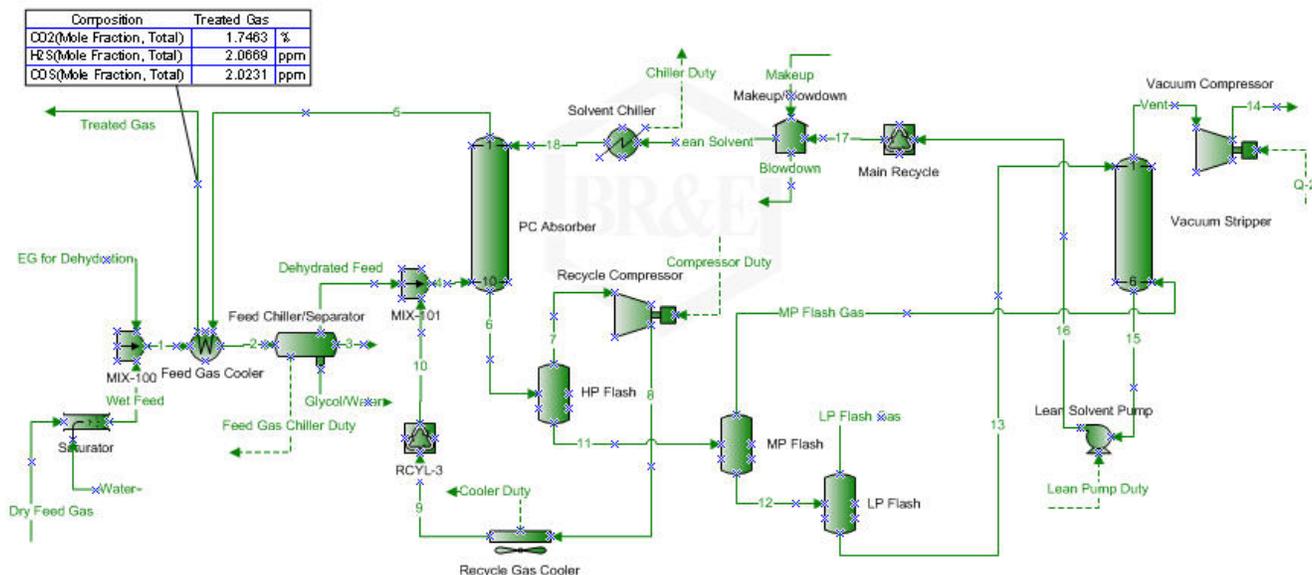


Figure 4 – Acid Gas Removal with Chilled PC

### Acid Gas Removal

All of the solvents are able to reduce the CO<sub>2</sub> in the treated gas to 1.75%, and all with the exception of PC are able to reduce the H<sub>2</sub>S plus COS content to less than 0.5 ppm. The PC does, however, reduce the H<sub>2</sub>S and COS to a respectable 4 ppm. As discussed previously, PC is better suited to cases where the H<sub>2</sub>S content of the feed is 50 ppmv or less, or 200 ppmv using an improved vacuum stripping configuration. The current feed contains 500 ppm each of H<sub>2</sub>S and COS. The H<sub>2</sub>S and COS removal could be improved by using additional stripping gas, either fuel gas or inert gas if available. A portion of the treated gas could also be used if economically feasible. In this example, about 10 MMSCFD of dry stripping gas would be required in addition to the 30 MMSCFD of MP Flash Gas to achieve the 0.5 ppm H<sub>2</sub>S plus COS specification.

### Equipment Required

Table 5 lists the major equipment required for each case. The duties and horsepowers calculated by ProMax are rounded up for easier comparison. The Methanol process requires the most equipment. However, the exchanger and compressor sizes are significantly smaller than the corresponding equipment for the other physical solvents. The Propylene Carbonate process requires the least equipment. Exchanger duties, pump power requirements and compressor power are considerably lower for the Chilled DEPG and Chilled NMP cases as compared to the unchilled processes due to much lower circulation rates required. The required circulation rates are included in Table 5.

Table 5 – Equipment Required for Each Case

	MeOH	DEPG	Chilled DEPG	NMP	Chilled NMP	Chilled PC
Total Circulation Rate (sgpm)	4623	15,282	5856	16,195	6188	6085
Absorber Diameter (ft)	14.5	25	16.5	24.5	15.5	17
Stripper 1 Diameter (ft)	13	25	16	25.5	16	18.5
Stripper 2 Diameter (ft)	10	None	None	None	None	None
Stripper 3 Diameter (ft)	2	None	None	None	None	None
Reboiler 1 (MMBtu/hr)	27	137	65	172	68	None
Reboiler 2 (MMBtu/hr)	2	None	None	None	None	None
Condenser (MMBtu/hr)	11	52	46	25	25	None
Chiller or Lean Cooler (MMBtu/hr)	22	93	26	156	52	2
Feed Chiller (MMBtu/hr)	None	None	None	None	None	10
Lean/Rich Exch (MMBtu/hr)	89	751	458	666	444	None
Feed/Product Exch 1 (MMBtu/hr)	7	None	6	None	6	6
Feed/Product Exch 2 (MMBtu/hr)	7	None	None	None	None	None
Cross Exch (MMBtu/hr)	0.1	None	None	None	None	None
Recycle Compressor (hp)	182	606	240	643	223	246
Recycle Cooler (MMBtu/hr)	None	2	0.4	2	0.3	0.4
Lean Pump (hp)	610	7208	2762	7171	2740	2623
Semi-Lean Pump (hp)	750	None	None	None	None	None
Rich Pump 1 (hp)	1	None	None	None	None	None
Rich Pump 2 (hp)	18	None	None	None	None	None
Vacuum Compressor (hp)	None	None	None	None	None	5490
Separators	3	4	4	4	4	4

### Power Requirements

Table 6 summarizes the duty and power requirements as calculated by ProMax for the various solvents to achieve 1.75% CO<sub>2</sub> and less than 0.5 ppmv H<sub>2</sub>S + COS in the treated gas (or 4 ppm H<sub>2</sub>S + COS for PC). Extremely low operating temperatures in the Methanol process result in the lowest required circulation rate, and lowest net power requirement. The highest net power requirement is for the PC since the vacuum compressor is required. A higher vacuum pressure would result in a much lower vacuum compressor duty. The total heat exchanger duty required for PC is lower than the other solvents due to a lower chiller duty and no reboiler or condenser.

The circulation rates for the unchilled versions of the DEPG and NMP processes are much higher than for the chilled processes. The higher circulation rates result in considerably higher pump power requirements and reboiler duty requirements. Solvent losses are not significant except for Methanol and unchilled NMP. If a water wash had been used, most of the MeOH and NMP solvent losses could have been recovered.

Table 6 – Results of Solvent Comparisons Using ProMax

	<b>MeOH</b>	<b>DEPG</b>	<b>Chilled DEPG</b>	<b>NMP</b>	<b>Chilled NMP</b>	<b>Chilled PC</b>
Total Circulation Rate (sgpm)	4623	15,282	5856	16,195	6188	6085
Chiller Temperature (°F)	-21	-	0	-	5	5
Chiller Duty (MMBtu/hr)	21.6	-	25.9	-	52.1	1.7
Reboiler Duty (MMBtu/hr)	28.1	136.6	64.8	171.5	67.9	-
Reboiler Steam (lb/hr)	30,191	149,526	70,910	188,204	74,464	-
Hydrogen Losses (% of Feed)	0.3	0.13	0.04	0.14	0.03	0.05
Solvent Losses (lb/hr)	3224*	5	Nil	417*	8	5
Net Power Required (hp)	1561	7814	3002	7814	2963	8358
Weight % Lean Solvent	97.1	98.0	98.0	95.5	95.5	99.8

\*No water wash was used

### SUMMARY AND CONCLUSIONS

This simple comparison shows that the Methanol process requires the lowest circulation rate and lowest net power, but requires the most equipment. Stripping gas and a vacuum compressor are required for the chilled PC because thermal regeneration (i.e. reboiler) could not be used. Furthermore, PC cannot be used for selective H<sub>2</sub>S removal.

Other physical solvent comparisons have been made previously. In a detailed report, Doctor et al. [14] compared Selexol and Rectisol processes for an IGCC application and found the Selexol treating to be less costly than Rectisol for fuel-cycle CO<sub>2</sub> sequestering. Bucklin and Schendel (1984) [6] compared PC and Selexol and found that Selexol has the advantage in applications involving both H<sub>2</sub>S and CO<sub>2</sub> removal in hydrocarbon systems. They also found that Fluor Solvent and Selexol were both suitable for CO<sub>2</sub> removal only.

All of the physical solvents can be used successfully for bulk removal of CO<sub>2</sub>. A detailed analysis must be performed to determine the most economical choice of solvent based on the product requirements. Feed gas composition, minor components present, and limitations of the individual physical solvent processes all are important factors in the selection process. Engineers can easily perform this selection process using verified process simulation programs such as ProMax.

### ACKNOWLEDGMENTS

The authors wish to express their appreciation to Kevin Lunsford of Bryan Research & Engineering, Inc. for his assistance, comments, and suggestions for this paper. Also, the authors would like to express their appreciation to Chao Chen of WorleyParsons for providing valuable information concerning CO<sub>2</sub> capture technology for IGCC Power Plants.

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