SI ERRATA PAGES (Errata highlighted)

SEC 14 — Pages 3 through 8

SEC 16 — Pages 1 and 2

SEC 19 — Pages 9 through 12

SEC 20 — Pages 17 and 18
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SEC 26 — Pages 1 through 34

nation of desuperheating and constant temperature condensing. This fact must be considered for proper design of the condenser.

System pressure drop — Some typical values for pressure drops that must be considered are:

Condenser pressure drop	20 to 50 kPa
Line hydraulic losses	
Evaporator to Compressor*	0.7 to 10 kPa
Compressor to Condenser	0.7 to 14 kPa
Condenser to Receiver	3.5 to 7 kPa

* This is an important consideration in refrigeration services with low suction pressure to compressor.

Refrigeration Stages

Refrigeration systems utilizing one, two, three, or four stages of compression have been successfully operated in various services. The number of levels of refrigeration generally depends upon the number of compression stages required, interstage heat loads, economics, and the type of compression.

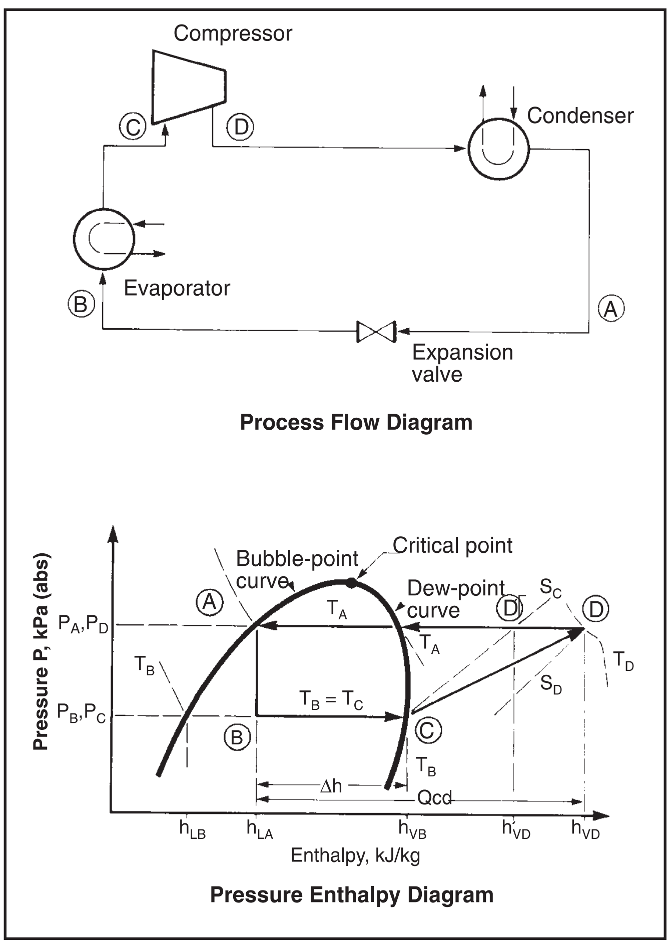
One-stage system — A typical one-stage refrigeration system is shown in Fig. 14-3 where the data are for pure propane refrigerant. Fig. 14-4 illustrates a process application of a single level chiller and the associated cooling curve.

Two-stage system — Savings in the 20% range can often be achieved with a two-stage refrigeration system and interstage flash economizer. Additional savings can be realized by removing process heat at the interstage level rather than at the low stage level. A typical two-stage system with an intermediate load is shown in Fig. 14-5 with data for pure propane.

Three-stage system — Additional power savings can be achieved by using a three-stage compression system. As with a two-stage system, flash economization and/or an intermediate heat load can be used. The savings, while not as dramatic as the two stage versus one-stage, can still be significant enough to justify the additional equipment. A typical three stage propane system is shown in Fig. 14-6.

System configuration — Energy consumption is frequently reduced as the number of stages is increased. For a propane refrigeration system, Fig. 14-7 illustrates the effect of

FIG. 14-2
Process Flow Diagram and Pressure-Enthalpy Diagram



Process Flow Diagram

Pressure Enthalpy Diagram

FIG. 14-3
One-Stage Refrigeration System

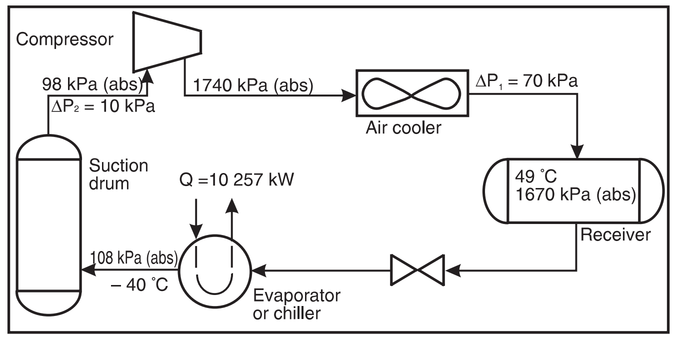
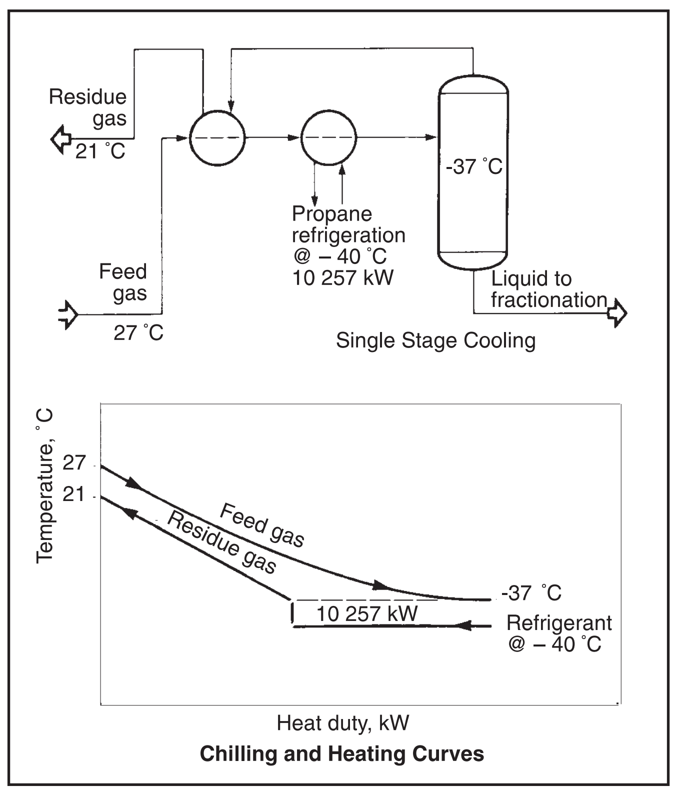


FIG. 14-4
Single-Stage Cooling, Chilling and Heating Curves



Single Stage Cooling

Chilling and Heating Curves

FIG. 14-5
Two-Stage Refrigeration System

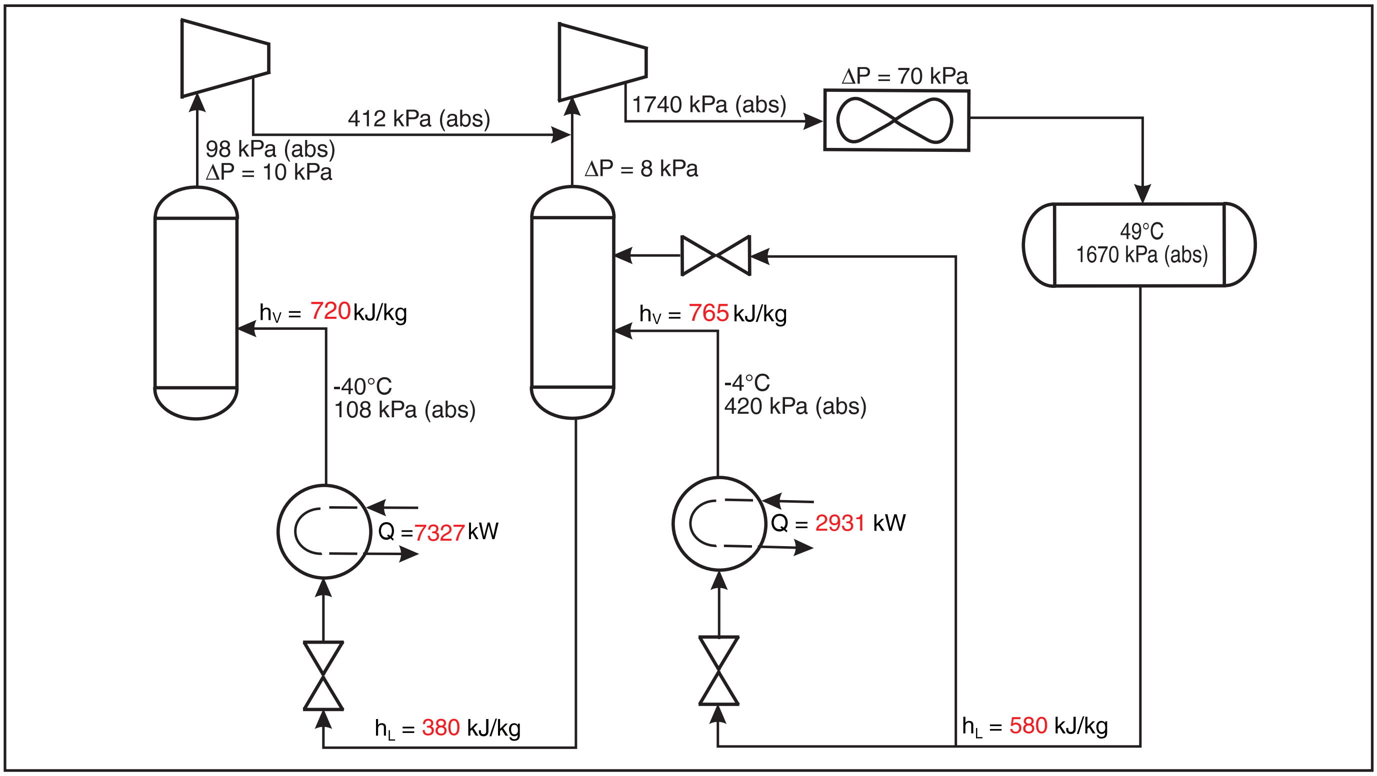
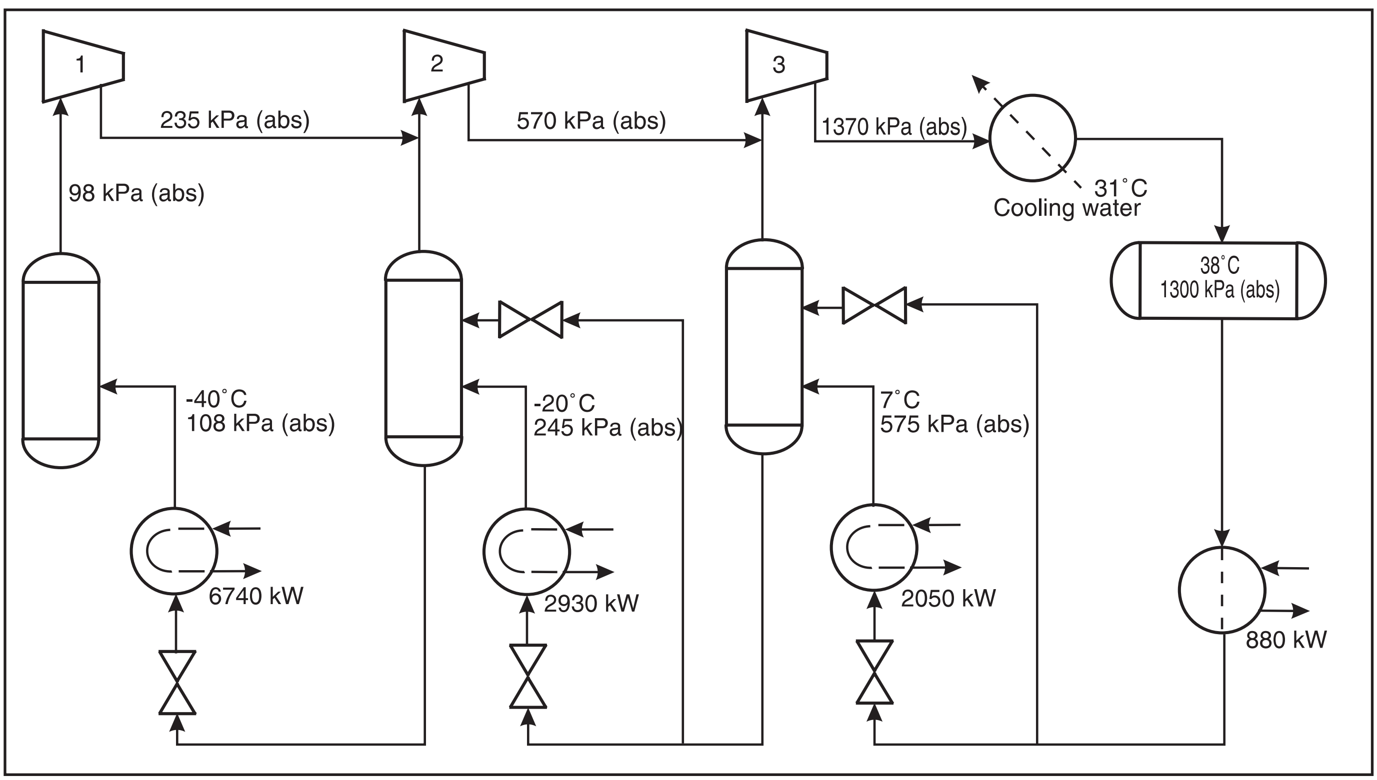


FIG. 14-6
Three-Stage Refrigeration System



interstages without using refrigeration at intermediate levels. However, the installation cost of such refrigeration systems increases as the number of stages increases. The optimum overall cost will be a function of the specific system and has to be determined for a set of economic criteria.

The compression power for refrigeration can be reduced further by shifting refrigerant load from cooler levels to warmer levels. Fig. 14-8 shows a refrigeration system using two levels of chilling. The gas is initially chilled to –1 °C with –4 °C propane and then to –37 °C with –40 °C propane. The selection of the –4 °C level results from equal compression ratios for each stage. The interstage pressure and corresponding refrigerant temperature may be fixed by either equipment or process conditions. Equal compression ratios per stage are chosen whenever possible to minimize power.

Example 14-1 — Calculate the power and condenser duty required for the process shown in Fig. 14-8 using propane refrigeration. Design condensing temperature is 49 °C. The pressure drop from the chillers to the compressor suction is 10 kPa. The pressure drop from compressor discharge to the receiver is 70 kPa.

Solution Steps:

In order to determine the interstage refrigeration level for a two-stage system, determine the ratio per stage:

$$r = \left(\frac{P_d}{P_s}\right)^{1/n} \qquad \textbf{Eq 14-9}$$

From the propane vapor pressure curve:

$$P_d = 1670 \text{ kPa (abs)} + 70 \text{ kPa} = 1740 \text{ kPa (abs)}$$

$$P_s = 108 \text{ kPa} - 10 \text{ kPa} = 98 \text{ kPa (abs)}$$

$$r = \left(\frac{1740}{98}\right)^{1/2} = 4.21$$

Thus the second stage suction pressure is:

$$P_{s2} = (98)(4.21) = 412 \text{ kPa}$$

The first stage discharge pressure is:

$$P_{dl} = 412 + 8 = 420 \text{ kPa}$$

From the vapor pressure curve for propane, the refrigeration temperature at 420 kPa (abs) is –4 °C. Converting kW duties to kJ/h and substituting enthalpy values from Section 24, into Equation 14-5, we find the refrigerant flowrate through each chiller:

$$m_1 = \frac{(26.4)(10^6)}{(720 - 380)} = 77\,647 \text{ kg/h}$$

$$m_2 = \frac{(10.6)(10^6)}{(765 - 530)} = 45\,106 \text{ kg/h}$$

where m_1 is the flowrate through the first stage chiller, and m_2 is the flowrate through the second stage chiller.

Liquid flow to the first-stage chiller (77 647 kg/h) is provided by flashing the liquid refrigerant from the refrigerant receiver at 49 °C and bypassing the second-stage chiller.

In order to determine the flow of liquid refrigerant from the receiver, consider the heat and material balances shown in Fig. 14-9. Here, let m_b (kg/h) denote the refrigerant bypassing the second-stage chiller. The chiller produces 45 106 kg/h of refrigerant vapor at –4 °C. These vapors flow through the second stage suction drum, and leave overhead. The liquid required from the second stage flash drum for the first stage chiller comes from the quantity m_b.

By material balance, we find the vapors leaving the second stage suction drum as m_b + 45 106 – 77 647 or m_b – 32 541 kg/h. By heat balance around the suction drum, we can determine the amount of refrigerant, m_b:

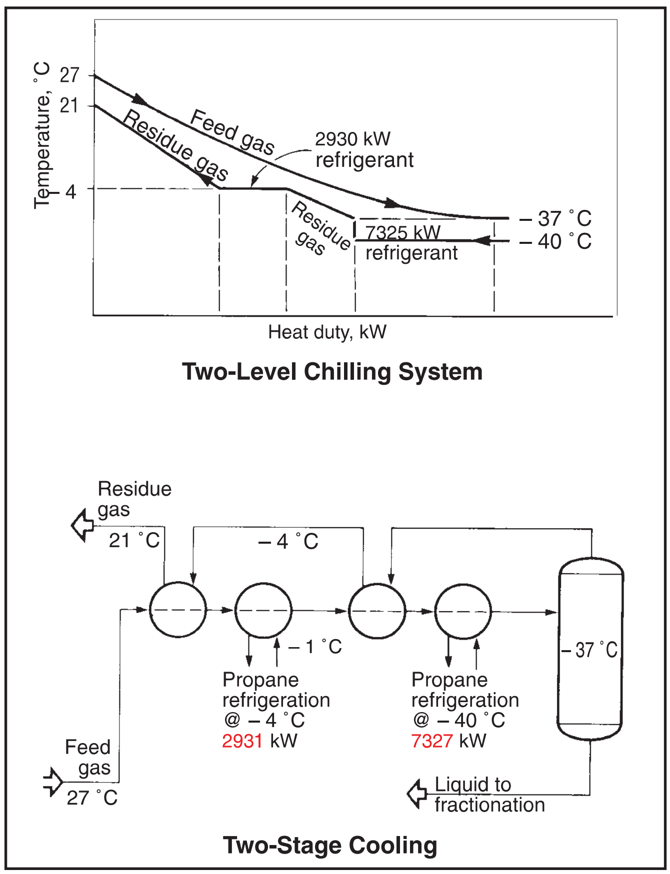
$$(m_b - 32\,541)(765) + (77\,647)(380) = m_b(530) + (45\,106)(765)$$

$$m_b = 127\,209 \text{ kg/h}$$

FIG. 14-7
Effect of Staging on a Propane Refrigeration System

	Stages, n		
	1	2	3
Refrigeration Duty, kW	293	293	293
Refrigeration Temperature, °C	–40	–40	–40
Refrigerant Condensing Temperature, °C	38	38	38
Compression Requirements, kW	218	176	167
Reduction in BP, %	Base	19.2	23.3
Condenser Duty, kW	511	469	462
Change in condenser duty, %	Base	–8.2	–9.6

FIG. 14-8
Two-Level Chilling, Two-Stage Cooling System



In order to calculate isentropic work for the first stage, it is necessary to determine the isentropic enthalpy at 412 kPa (abs). Fig. 24-20, the first stage inlet entropy equals 3.85 kJ/kg · K, and the corresponding isentropic enthalpy at 412 kPa (abs) is 782 kJ/kg.

The ideal change in enthalpy = 782 – 720 = 62 kJ/kg

For propane refrigerant k = 1.13, compression ratio, r, of 4.21 and the isentropic efficiency, η_i of 0.75, the required compression power for the first stage is obtained from Equation 14-7b:

$$BP_1 = \frac{(62)\,(77\,647)}{(0.75)\,(3\,600)} = 1783 \text{ kW}$$

Using Equation 14-7a we determine the first stage discharge enthalpy is:

$$h_{vld} = \frac{62}{0.75} + 820 = 803 \text{ kJ/kg}$$

A material balance around the second compression stage yields the total refrigerant flow:

$$m_T = m_1 + (m_b - 32\,541) = 77\,647 + (127\,209 - 32\,541)$$
$$= 172\,315 \text{ kg/h}$$

A heat balance at the second compression stage entrance yields the second stage inlet enthalpy:

$$h_{v2s} = \frac{(803)\,(77\,647) + (765)\,(127\,209 - 32\,541)}{(172\,315)}$$
$$= 782 \text{ kJ/kg}$$

From Fig. 24-27, the inlet entropy at 412 kPa (abs) and 782 kJ/kg is 3.85 kJ/(kg · K), and the isentropic enthalpy at 1740 kPa (abs) is 860 kJ/kg.

Substituting into Equation 14-6, the ideal enthalpy change across the second stage as:

$$\Delta h = 860 - 782 = 78 \text{ kJ/kg}$$

The required compression power for the second stage is determined from Equation 14-7b:

$$BP_2 = \frac{(78)\,(172\,315)}{(0.75)\,(3600)} = 4978 \text{ kW}$$

Hence, the compression required for the two-stage propane refrigeration system becomes:

$$BP_T = 1783 + 4978 = 6761 \text{ kW}$$

Using Equation 14-7a, the second stage discharge enthalpy is:

$$H_{V2d} = \frac{78}{0.75} + 782 = 886 \text{ kJ/kg}$$

Substituting into Equation 14-8 yields the condenser duty for the two-stage propane refrigeration system:

$$Q_{cd} = (886 - 530)\,(172\,315)$$
$$= (6.134)\,(10^7) \text{ kJ/h} = 17\,039 \text{ kW}$$

From Fig. 24-27 the second stage discharge temperature at 1740 kPa and enthalpy of 886 kJ/kg is 80 °C.

Condensing Temperature

Condensing temperature has a significant effect on the compression power and condensing duty requirements. Mehra[3] illustrated the effect of the condensing temperature on refrigeration requirements for one, two, and three stage systems. Results for a one-stage propylene refrigeration system are summarized in Fig. 14-10.

Fig. 14-10 illustrates that the colder the condensing temperature, the lower the power requirements for a given refrigeration duty. Traditionally, the heat sinks for most refrig- eration systems have been either cooling water or ambient air. If cooling water or evaporative condensing is utilized, a 27 to 38 °C temperature can be achieved. Section 11 provides wet and dry bulb temperature data. Fig. 14-10 also indicates, to a certain extent, the effect on operations between summer and winter conditions as well as between day and night operations.

Refrigerant Subcooling

Subcooling liquid refrigerants is common in refrigeration systems. Subcooling the refrigerant reduces the energy requirements. It is carried out when an auxiliary source of cooling is readily available, and the source stream needs to be heated. Subcooling can be accomplished by simply installing a heat exchanger on the appropriate refrigerant and process streams.

FIG. 14-9
Data for Heat and Material Balances

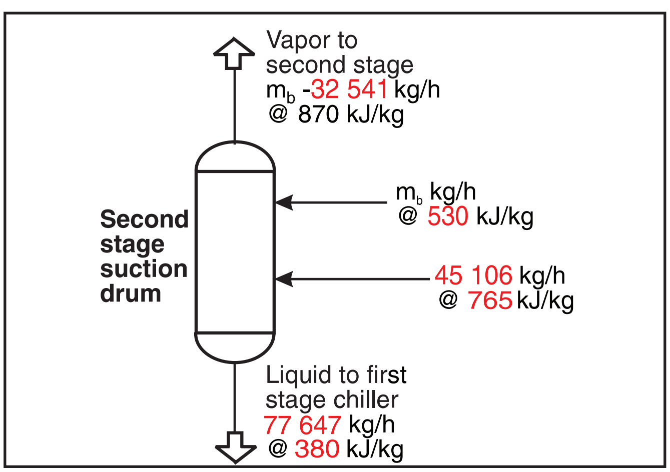


FIG. 14-10
Effect of Condensing Temperature

Condensing Temperature, °C	16	27	38	49	60
Refrigeration Duty, kW	293	293	293	293	293
Refrigeration Temperature, °C	–46	–46	–46	–46	–46
Compression Requirement, kW	157	199	248	320	413
Change in BP, %	–36.6	–19.8	Base	28.8	66.4
Condenser Duty, kW	451	492	539	613	709
Change in Condenser Duty, %	–16.3	–8.7	Base	13.6	31.5

Example 14-2 — Consider installing an 880 kW subcooler on the liquid propane refrigerant from the receiver at 49 °C in Example 14-1 for the two-stage propane refrigeration system. The second stage of this system is shown in Fig. 14-11.

Solution Steps:

By performing the heat balance around the subcooler and the second stage suction drum, the liquid refrigerant flowrate to the subcooler is determined to be 158 624 kg/h. When comparing this to the earlier flowrate of 172 315 kg/h, the refrigerant flow is reduced by 13 691 kg/h.

By heat balance around the subcooler, we determine the enthalpy of liquid propane refrigerant leaving the subcooler is 510 kJ/kg which corresponds to a temperature of 43 °C.

The flowrate of refrigerant through the second stage chiller becomes

$$m_2 = \frac{(10.6)\,(10^6)}{(765 - 510)} = 41\ 569 \text{ kg/h}$$

As a result of subcooling, the flow of refrigerant through the second stage chiller has been reduced from 45 106 kg/h to 41 569 kg/h. The lower flowrates result in reduced compression power, condenser duty, and reduced size of piping and equipment. These benefits must be balanced against the installed cost of the subcooler exchanger.

Refrigerant For Reboiling

Refrigerants have been successfully used for reboiling services wherever applicable conditions exist. Reboiling is similar in concept to subcooling — heat is taken out of the refrigeration cycle.

In reboiling service, the heat removed from the refrigerant condenses the refrigerant vapor at essentially constant temperature and pressure. The liquid refrigerant produced in a reboiler service is flashed to the next lower pressure stage to produce useful refrigeration. The refrigerant condensing pressure is a function of the reboiling temperature.

Refrigerant Cascading

In the cascading of refrigerants, warmer refrigerants condense cooler ones. Based on the low temperature requirements of a process, a refrigerant that is capable of providing the desired cold temperature is selected. For example, the lowest attainable temperature from ethane refrigerant is –85 °C (for a positive compressor suction pressure), whereas the lowest temperature level for propane is –40 °C (for a similar positive pressure).

In a refrigeration cycle, energy is transferred from lower to higher temperature levels economically by using water or ambient air as the ultimate heat sink. If ethane is used as a refrigerant, the warmest temperature level to condense ethane is its critical temperature of about 32 °C. This temperature requires unusually high compression ratios — making an ethane compressor for such service complicated and uneconomical. Also in order to condense ethane at 32 °C, a heat sink at 29 °C or lower is necessary. This condensing temperature is a difficult cooling water requirement in many locations. Thus a refrigerant such as propane is cascaded with ethane to transfer the energy from the ethane system to cooling water or air.

An example of a cascaded system is shown in Fig. 14-14, where an ethane system cascades into a propane system. The condenser duty for the ethane system is 9000 kW. This duty becomes a refrigeration load for the propane system along with its 6740 kW refrigeration at –40 °C. Therefore, the propane refrigeration system has to be designed to provide a total of 15 740 kW at –40 °C in addition to 2930 kW at –20 °C and 2050 kW at 7 °C.

Freon (CFC) Refrigerant Phase Out

Clorinated fluorocarbons (commonly called Freon) have been used for many years as effective refrigerants in many applications. However, the stability of these compounds, coupled with their chlorine content, has linked them to the depletion of the earth's protective ozone layer. As a result, these compounds have been phased out of production and usage globally. Hydrofluorocarbons (HFC) have been developed as an alternative.

Refrigerant HFC-410a has been developed to replace chlorodifluoromethane (R-22). This compound is reasonably close to R-22 in performance. Fig. 14-12 shows a comparison of HFC-410a and R-22. The refrigerant power requirement is quite similar but the operating pressures are higher for HFC-410a.

HFC-134a has been developed to replace dichlorodifluoromethane (R-12). This compound is reasonably close to R-12 in performance but differences in equipment design and operation must be taken into account in the replacement. Fig. 14-13 shows a comparison of HFC-134a and R-12 for an example application. One of the important differences is the higher compression ratio necessary for this refrigerant.

Refrigerant Properties

Physical properties of pure component refrigerants in common use are given in Fig. 14-15. The vapor pressure curves for ethane, ethylene, propane, prpylene, and Refrigerant 22 (R-22) are available in Sections 23 and 24 or references 2, 5, 9, and 10. Figs. 14-35 through 14-37 contain properties for HFC-410a. Properties for HFC-134a are given in Figs. 14-38 through 14-40. References 12 and 13 contain additional data for these refrigerants.

Enthalpy data are necessary in designing any refrigeration system. Pressure-enthalpy diagrams for pure ethane, ethylene, propane, propylene, and R-22 are available in Section 24 of this data book or references 2, 5, 9, and 10. References 12 and 13 contain additional information for these refrigerants.

FIG. 14-11
Refrigerant Subcooling

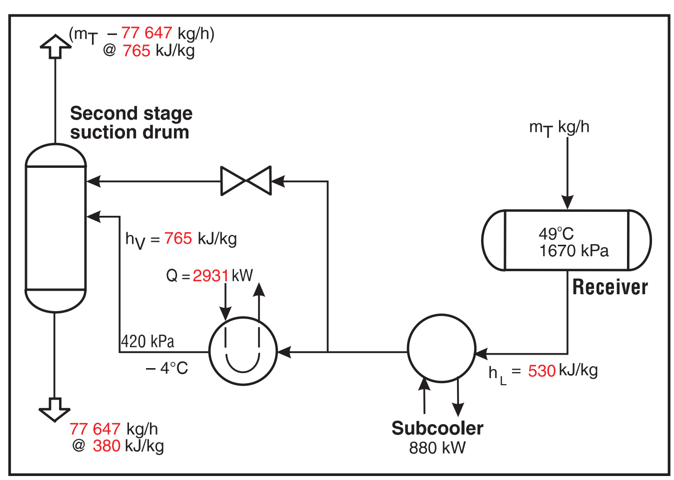


Fig. 14-12

Comparison Example of R-22 and HFC-410*

	R-22	HFC-410a
Psuction, kPa (abs)	214.4	353
Pdisch	1965	3068
Compr. Ratio	9.19	8.7
kW/MW	78.6	78.9
Condenser Load kJ/kJ	1.52	1.51
*–23 °C Chiller, 49 °C Condensing, 69 kPa (ga) Condenser DP		

FIG. 14-13

Theoretical Cycle Comparison of R-12 and HFC-134a*

	R-12	HFC-134a
Capacity (as % of R-12)	100	99.7
Compressor Exit temperature °C Exit pressure, kPa (abs)	 86.8 1348.6	 83.1 1473.4
Compression ratio	4.1	4.7
*Conditions: Condenser, 54.4 °C; Evaporator, 1.7 °C; Comp. Suction, 26.7 °C; Expansion Device, 51.7 °C		

Power and Condenser Duty Estimation

Since many gas processing plants require mechanical refrigeration, generalized charts[5] were developed to aid in a modular approach for designing refrigeration systems.

Because of the complexity of generalizing refrigeration systems, the charts have been developed for four of the most common refrigerants: ethylene, propylene, propane, and Refrigerant 22.

In order to apply these curves to most of the commercially available compressors, a polytropic efficiency of 0.77 was assumed. The polytropic efficiency was converted into an isentropic efficiency[1] to include the effects of compression ratio and specific heat ratio ($k = C_p/C_v$) for a given refrigerant. For well balanced and efficient operation of the compressor, an equal compression ratio between stages was employed.

The refrigeration level is defined as the temperature of the dew point vapor leaving the evaporator. The pressures at the compressor suction and side load inlet nozzles were adjusted by 10 kPa to allow for pressure drop. These charts also include a 35 kPa pressure drop across the refrigerant condenser for ethylene, and a 70 kPa drop for propane, propylene, and Refrigerant 22.

Before developing any system, one must define refrigerant temperature and condensing temperature of the refrigerant based on the medium used for condensing.

To achieve maximum energy conservation and minimum energy cost, it is necessary to match the process conditions and refrigeration compressor design to obtain the best efficiency.

After defining the lowest refrigerant level and the condensing temperature, the pressure at the evaporator and condenser can be established from the vapor-pressure curve for a specific refrigerant. All examples and data in this section are based upon pure component properties. In practice, pure hydrocarbon refrigerants are not always available. Impurities may cause significant deviations in design and performance.

One-stage systems — Figs. 14-16 through 14-20 provide data for estimating gas power and condenser duty requirements for one-stage refrigeration systems using ethylene, propane, propylene, R-22, and HFC 410a refrigerants.

Two-stage systems — The data for estimating gas power and refrigerant condenser duty requirements for two-stage refrigeration systems utilizing ethylene, propane, propylene, R-22, and HFC 410a are shown in Figs. 14-22 through 14-26.

Three-stage systems — The data for estimating gas power and condenser duty requirements for three-stage refrigeration systems utilizing ethylene, propane, propylene, and R-22 are presented in Figs. 14-27 through 14-31.

Example 14-3 — Estimate the power and condenser duty requirements for a single stage propylene refrigeration system that will provide 26.4 (10^6) kJ/h of process chilling at a refrigerant level of –29 °C.

Solution Steps

The unit BP for this example from Fig. 14-19 is 565 kW per MW of refrigeration duty at an evaporator temperature of –29 °C and a condenser temperature of 38 °C. And, from Fig. 14-19, the condenser duty factor equals 1.565 MW per MW of refrigeration duty for the same evaporator and condenser temperatures. Hence, the total power and condenser duty are:

$$BP = (565)(7.325) = 4\ 139 \text{ kW}$$

$$Q_{cd} = (7325)(1.565) = 11\ 464 \text{ kW}$$

Heat exchanger economizing — An alternative to flash economizing of the refrigeration cycle is to use a heat exchanger to accomplish an economizing step. Fig. 14-21 shows an example economizer using a heat exchanger. The heat exchanger is a chiller which uses some of the condensed refrigerant to subcool the balance of the condensed refrigerant stream. The refrigerant used for the chilling is then fed to the interstage (or second stage) of the refrigeration compressor. The subcooled refrigerant is then used for process chillers. The subcooled refrigerant produces less unusable vapor when flashed to suction drum conditions than a refrigerant stream that is not subcooled. Thus the use of the heat exchanger effectively shifts vapor from the low stage of compression to the high stage, thus saving power. The resultant process impact is very similar to the flash economization previously discussed.

Design and Operating Considerations

The following are some of the important parameters that should be considered while designing any refrigeration system to provide a safe, reliable, and economical operation.

Oil removal — Oil removal requirements from evaporators are related to the type of the refrigerant, lubricant, evaporator, and compressor used in the refrigeration cycle. Fig. 14-32 illustrates the application of an oil reclaimer in a propane refrigerant cycle. In order to remove oil from the refrigerant, a slip

SECTION 16

Hydrocarbon Recovery

Gas processing covers a broad range of operations to prepare natural gas for market. Processes for removal of contaminants such as H_2S, CO_2 and water are covered extensively in other sections of the Data Book. This chapter will cover the processes involved in recovering light hydrocarbon liquids either for sale when their value as liquids is higher than their value as gas components or they must be removed to avoid condensation. The equipment components included in the processes described are covered in other sections of the Data Book. This section will bring those components together in process configurations used for liquid production.

INTRODUCTION

The recovery of light hydrocarbon liquids from natural gas streams can range from simple dew point control to avoid liquid formation to deep ethane extraction. The desired degree of liquid recovery has a profound effect on process selection, complexity, and cost of the processing facility.

The term NGL (natural gas liquids) is a general term which applies to liquids recovered from natural gas and as such refers to ethane and heavier products. The term LPG (liquefied petroleum gas) describes hydrocarbon mixtures in which the main components are propane, iso and normal butane, propene and butenes. Typically in natural gas production olefins are not present in LPG.

Typically, modern gas processing facilities produce a single ethane plus product (normally called Y-grade) which is often sent offsite for fractionation and processing. Whether accomplished on-site or at another facility, the mixed product will typically be fractionated to make products such as purity ethane, ethane-propane (EP), commercial propane, isobutane, normal butane, mixed butanes, butane-gasoline (BG), and gasoline (or stabilized condensate). The degree of fractionation and the liquid products is market and geographically dependent.

Early efforts in the 20th century for liquid recovery involved compression and cooling of the gas stream and stabilization of a gasoline product. The lean oil absorption process was developed in the 1920s to increase recovery of gasoline and produce products with increasing quantities of butane. These gasoline products were, and still are, sold on a Reid vapor pressure (RVP) specification. Vapor pressures such as 69 or 83 kPa (abs) are common specifications for gasoline products. To further increase production of liquids, refrigerated lean oil absorption was developed in the 1950s. By cooling the oil and the gas with refrigeration, the absorber vapor outlet is leaner and propane product can be recovered. With the production of propane from lean oil plants, a market developed for LPG as a portable liquid fuel.

In lieu of using lean oil, refrigeration of the gas can be used for propane and heavier component recovery. The use of straight refrigeration typically results in a much more economical processing facility than using lean oil. The chilling of the gas can be accomplished with mechanical refrigeration, absorption refrigeration, expansion through a J-T valve, or a combination. In order to achieve still lower processing temperatures, cascade refrigeration, mixed refrigerants, and most significantly turboexpander technologies have been developed and applied. With these technologies, recoveries of liquids can be significantly increased to achieve deep ethane recoveries. Early ethane recovery facilities targeted about 50% ethane recovery. As processes developed, ethane recovery efficiencies have increased to well over 90% in well integrated facilities.

In some instances heavy hydrocarbons are removed to control the hydrocarbon dew point of the gas and prevent liquid from condensing in pipeline transmission and fuel systems. In this case the liquids are a byproduct of the processing and if no market exists for the liquids, they may be used as fuel. Alternatively, the liquids may be stabilized and marketed as condensate.

GAS COMPOSITION

The gas composition has a major impact on the economics of NGL recovery and the process selection. In general, gas with a greater quantity of liquefiable hydrocarbons produces a greater quantity of products and hence greater revenues for the gas processing facility. Richer gas also entails larger refrigeration duties, larger heat exchange surfaces and higher capital cost for a given recovery efficiency. Leaner gases generally require more severe processing conditions (lower temperatures) to achieve high recovery efficiencies and incur a higher cost per unit of liquid product.

Gases are typically characterized by the cubic meters of recoverable hydrocarbons per thousand cubic meters of gas. This is commonly expressed as “liquid content.” Liquid content was traditionally meant to apply to propane and heavier components but is often used to include ethane. The liquid content of a gas can be calculated as shown in Example 16-1.

The other major consideration in the evaluation of NGL recovery options is the specification of the residue sales gas. Sales specifications are usually concerned with a minimum Higher Heating Value (HHV) of the gas, but in some instances the maximum HHV can also be a consideration. The calculation of HHV is covered in Section 23 and in more detail in GPA Standard 2172, “Calculation of Gross Heating Value, Relative Density, and Compressibility Factor for Natural Gas Mixtures from Compositional Analysis.” In addition, for some gas sales the maximum and mininum Wobbe Number of the gas may be specified. For more information on the calculation of Wobbe Number, See Section 1 definitions.

Removal of liquids results in gas “shrinkage” and reduction of the HHV. This shrinkage represents a loss of revenue for the gas sales which must be considered in the economics of an NGL recovery plant. In general, sales gas specifications set the minimum HHV at 35.4-37.3 MJ/m^3. Thus, if any components such as nitrogen or CO_2 are present in the gas, sufficient ethane and heavier components must remain in the gas to meet the heating value specification. If little nitrogen or CO_2 is present in the gas, the recovery level of the ethane and heavier components is then limited by markets, cost of recovery, and gas value. The calculation of HHV and shrinkage cost is illustrated in Example 16-1.

Example 16-1 — Find the liquid content of the gas mixture in Fig. 16-1. Find the HHV of the feed gas and the HHV of the residue gas with the following NGL recovery efficiencies: C_2 – 90%, C_3 – 98%, iC_4/nC_4 – 99%, C_5+ – 100%. What is the shrinkage cost at \$3.80/MkJ?

Solution Steps:

Solution is shown in Fig. 16-1.

From Fig. 23-2 obtain the m^3/kmol for each of the components. Multiply the mole fraction of each component (mole %/100) by the m^3/kmol for that component and divide by 0.02369 km^3/kmol to get the m^3 liq/1000 m^3 gas of each component. The total m^3 liq/1000 m^3 gas from Fig. 16-1 is 0.4169.

For the recoveries specified the net m^3/day and residue composition can be found as shown in Fig. 16-1. In order to compute the HHV of the two streams, the HHVs of each component are found in Fig. 23-2. Multiplying the individual HHVs by the mole % gives a total HHV of 41.628 for the feed gas and 36.260 for the residue gas.

The shrinkage volume can be found by the difference of the volume of the feed gas times the HHV and the volume of residue gas times its HHV. This volume is then multiplied by \$3.80/MkJ to get the shrinkage value of the NGLs.

Shrinkage Value = [(9.34 · 41.628) – (8.38 · 36.260)]

· \$3.80/MkJ = \$322 800/day

The value of the NGLs in \$/m^3 versus the value of the components in the residue gas in \$/m^3 or the "spread" between these values is the primary economic criteria for NGL recovery project evaluations.

FIG. 16-1
Solution to Example 16-1

LIQUID CONTENT CALCULATION

Component	Feed Gas Mole %	m^3/kmol	Available m^3/1000 m^3	Available m^3/day	Estimated Recovery %	Net m^3/day	Residue Gas Mole %
N_2	1.000						1.115
CO_2	3.000						3.346
C_1	85.000						94.808
C_2	5.800	0.08445	0.2077	1936	90	1742	0.647
C_3	3.000	0.08686	0.1102	1030	98	1009	0.067
IC_4	0.700	0.10322	0.0306	285	99	283	0.008
NC_4	0.800	0.09950	0.0337	315	99	311	0.009
IC_5	0.300	0.11552	0.0147	137	100	137	0.000
NC_5	0.200	0.11433	0.0097	90	100	90	0.000
C_6+ (Set as nC_6 for example)	0.200	0.12980	0.0110	103	100	103	0.000
Total	100.000		0.4169	3896		3675	100.000
MSm^3/day	9.34						8.38

SHRINKAGE CALCULATION

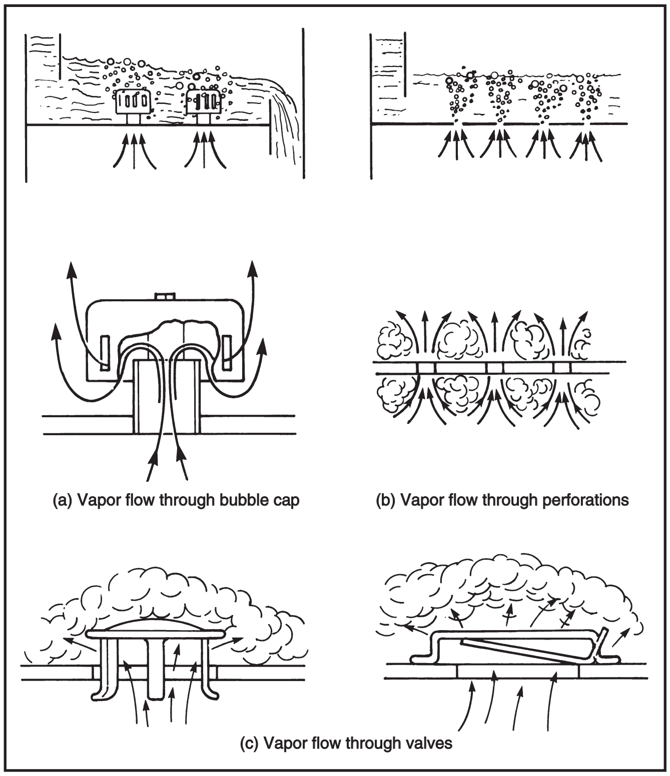
Component	Feed Gas Mole%	Residue Gas Mole %	HHV MJ/m^3	Feed Gas MJ/m^3	Residue Gas MJ/m^3
N_2	1.000	1.115	0.0	0.00	0.00
CO_2	3.000	3.346	0.0	0.00	0.00
C_1	85.000	94.808	37.707	32.051	35.749
C_2	5.800	0.647	66.067	3.832	0.427
C_3	3.000	0.067	93.936	2.818	0.063
IC_4	0.700	0.008	121.404	0.850	0.010
NC_4	0.800	0.009	121.792	0.974	0.011
IC_5	0.300	0.000	149.363	0.448	0.000
NC_5	0.200	0.000	149.656	0.299	0.000
C_6+	0.200	0.000	177.554	0.355	0.000
Total	100.000	100.000		41.628	36.260
MSm^3/day	9.34	8.38			

operating characteristics for a representative system. The vapor and liquid rates can vary independently over a broad range and the column will operate satisfactorily. At low vapor rates unsatisfactory tray dynamics may be characterized by vapor pulsation, dumping of liquid, or uneven distribution. At high vapor rates, the tower will eventually flood as liquid is entrained to the tray above or backed-up in the downcomers. At low liquid rates, poor vapor-liquid contact can result. High liquid rates can cause flooding and dumping as the liquid capacity of the downcomers is exceeded.

In order to handle higher liquid rates, more downcomer area is required. This is often achieved by using multiple pass trays. Multipass trays increase liquid handling capacity for a given diameter due to increased weir length and reductions in the weir crest. Fig. 19-12 shows various configurations beyond a one pass tray where the liquid phase is split into two to four flow paths to increase liquid handling capacity.

FIG. 19-9

Flow Through Vapor Passages[28]



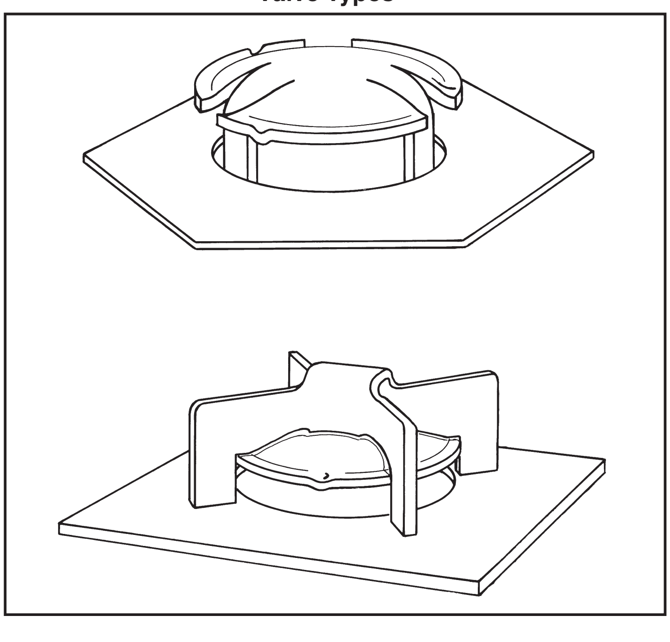
(a) Vapor flow through bubble cap

(b) Vapor flow through perforations

(c) Vapor flow through valves

FIG. 19-10

Valve Types[28]



Sizing

"C" factor method — Many design methods for sizing trayed fractionators have been used. Generally these methods are oriented toward liquid entrainment limitations or correlations for flooding limits. A simple method called the Souders and Brown equation[8] involves using a Stokes' Law type formula:

$$v_{max} = C \sqrt{\frac{\rho_L - \rho_v}{\rho_v}} \qquad \textbf{Eq 19-11}$$

Note that ρ_L and ρ_v are at flowing temperature and pressure.

The value of C can be found from Fig. 19-13 based on tray spacing and liquid surface tension. The column diameter is:

$$D_T = \sqrt{\frac{V_{max}}{v_{max}\,(0.7854)}} \qquad \textbf{Eq 19-12}$$

This method was originally developed for bubble cap trays and gives a conservative diameter, especially for other types of trays.

Nomograph method — Manufacturers of valve trays have developed design methods for their trays. Design procedures are made available[9, 10, 11] for preliminary studies. One such procedure starts with the nomograph in Fig. 19-14.[10] This is a simple relationship of liquid rate (GPM) and a quantity V_{load} defined as:

$$V_{load} = CFS \sqrt{\frac{\rho_v}{(\rho_L - \rho_v)}} \qquad \textbf{Eq 19-13}$$

FIG. 19-11

Limits of Satisfactory Tray Operation for a Specific Set of Tray Fluid Properties[8]

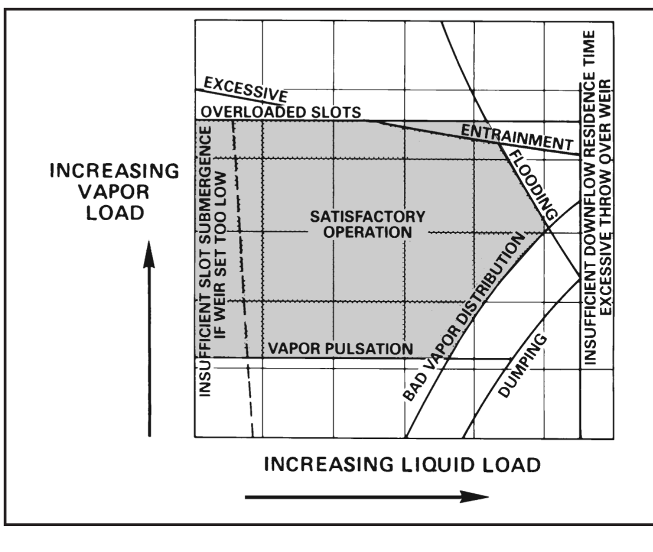
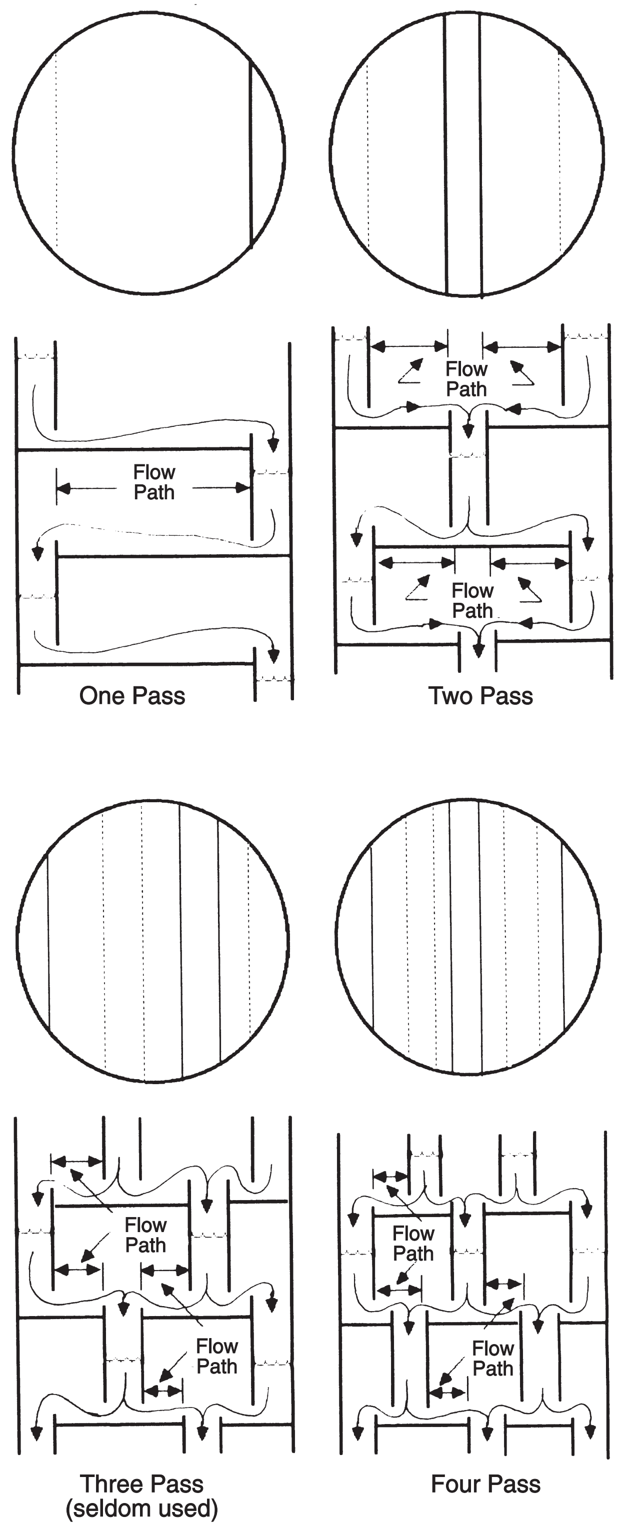


FIG. 19-12
Alternative Liquid Flow Paths



Simplified hand method — Tray vendors today provide computer programs to users to size both trayed and packed columns. These vendors should be contacted for copies of their programs for their products. The method included here is a hand method that can be used for preliminary sizing of trayed columns and to understand the key parameters that affect column sizing.

Fig. 19-14 is an approximation only and does not take into account foaming which is a major consideration in many systems. In order to compensate for foaming, a System Factor is used to adjust the vapor and liquid capacities (Fig. 19-15).

The downcomer velocity VD^*_{dsg} is found from Fig. 19-16. VD^*_{dsg} is corrected by the System Factor:

$$VD_{dsg} = VD^*_{dsg} \text{ (System Factor)} \qquad \textbf{Eq 19-14}$$

The other factor required for this design method is the vapor capacity factor CAF.

$$CAF = CAF_o \text{ (System Factor)} \qquad \textbf{Eq 19-15}$$

CAF_o is read from Fig. 19-17. In order to compute the column cross sectional area, three quantities are needed.

FIG. 19-13
Souders-Brown Correlation for Approximate Tower Sizing[8]

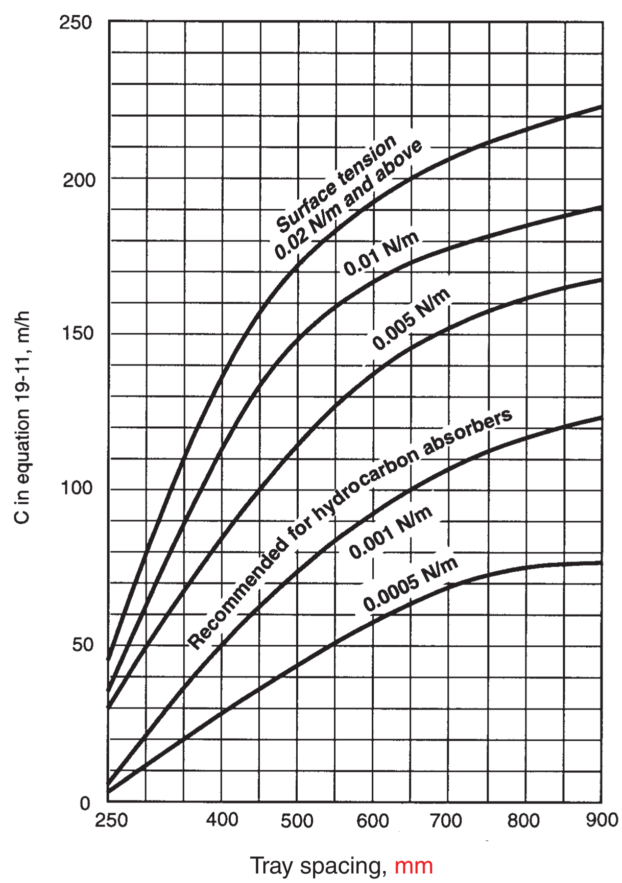
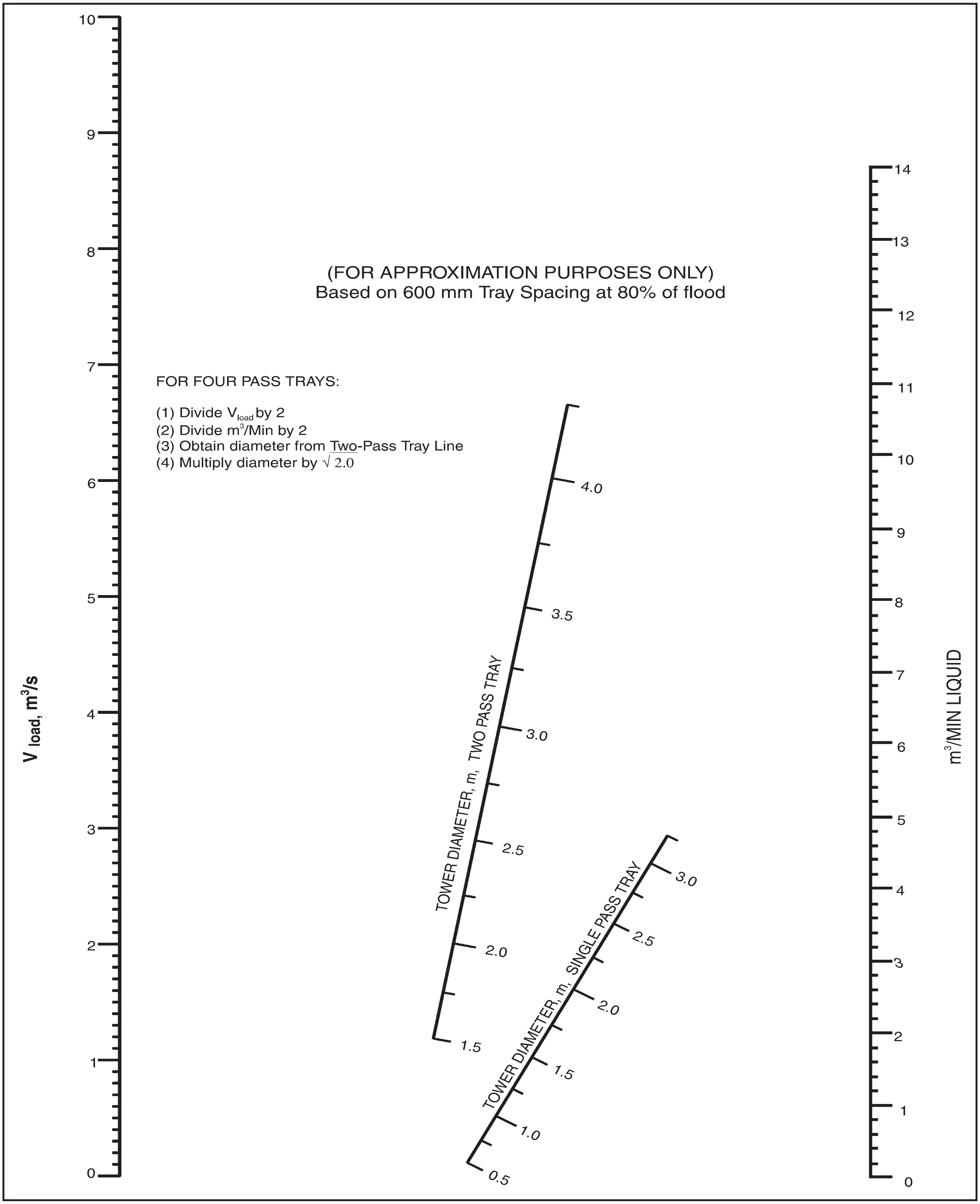


FIG. 19-14
Valve Tray Diameter[10]



The flow path length, FPL:

$FPL = 9\ D_T/NP$ **Eq 19-16**

D_T and NP are found from Fig. 19-14.

The active area, AAM:

$$AAM = \frac{V_{load} + [(GPM\ (FPL/530)]}{CAF \cdot FF}$$ **Eq 19-17**

FF, the flooding factor commonly used is 0.82 for most systems.

The downcomer area, ADM:

$ADM = GPM/(VD_{dsg} \cdot FF)$ **Eq 19-18**

If ADM is less than 11% of AAM, use 11% of AAM or double ADM, whichever is smaller.

The tower cross sectional area is then:

$ATM = AAM + 2\ (ADM)$ **Eq 19-19**

or

$$ATM = \frac{V_{load}}{0.78 \cdot CAF \cdot FF}$$ **Eq 19-20**

The larger of these two values is used. Then:

$D_T = \sqrt{ATM/0.7854}$ **Eq 19-21**

Example 19-3 — Determine the diameter of a depropanizer with the following data:

vapor rate: 1994 m^3/h
vapor density: 48 kg/m^3
liquid rate: 4.5m^3/min
liquid density: 461 kg/m^3
liquid surface tension: 0.0033 η/m
tray spacing: 61cm = 610 mm

"C" Factor Method

From Fig. 19-13: C ≅ 131

$$v_{max} = 131 \sqrt{\frac{461 - 48}{48}} = 384.3 \text{ m/h}$$ from Equation 19-11

$$D_T = \sqrt{\frac{1944}{384.3\ (0.7854)}} = 2.54 \text{ m} = 2540 \text{ mm}$$ from Equation 19-12

Nomograph (Fig. 19-14)

$$V_{load} = \frac{1994}{3600}\sqrt{\frac{48}{461 - 48}} = 0.1889 \text{ m}^3\text{/s}$$ from Equation 19-13

then from Fig. 19-14 @ GPM = 4.5 m^3/s

D_T ≅ 290 cm for a 1 pass tray = 2900 mm
229 cm for a 2 pass tray = 2290 mm

Detailed Method

$VD^*_{dsg} = 7.6\ m^3/min/m^2$ at $\rho_L - \rho_v = 413$

$$\text{System Factor} = \frac{2.93}{\left(\frac{413}{48}\right)^{0.32}} = 0.85 \text{ (Fig. 19-15)}$$

$VD_{dsg} = 7.6\ (0.85)$
$= 6.46\ m^3/min/m^2$

From Fig. 19-17:

$CAF_o = 0.126$ m/s

$CAF = (0.126)\ (0.85) = 0.107$ m/s

$$FPL = \frac{9\ (2.29)}{2} = 10.3 \text{ m}$$ from Equation 19-16

$$AAM = \frac{0.1889 + [4.5\ (10.3/530)]}{(0.107)\ (0.82)} = 3.15 \text{ m}^2$$ from Equation 19-17

$$ADM = \frac{4.5}{(6.46)\ (0.82)} = 0.85 \text{ m}^2$$ from Equation 19-18

$ATM = 3.15 + 2\ (0.849) = 4.85\ m^2$ from Equation 19-19

$$ATM = \frac{0.1889}{(0.78)\ (0.107)\ (0.82)} = 2.76 \text{ m}^2$$ from Equation 19-20

$$D_T = \sqrt{\frac{4.85}{0.7854}} = 2.48 \text{ mm} = 2480 \text{ mm}$$ from Equation 19-21

A comparison of the methods (rounded to the nearest 50 mm)

C Factor	2550 mm
Nomograph	2300 mm (2900 mm for single pass)
Detailed Method*	2500 mm

FIG. 19-15
System Factors[9]

Systems with foaming tendencies are taken into account by using a factor to derate the capacity of a given tray design. A list of the more common foaming systems and their recommended factor is below.

System	Factor
Absorbers (over –18 °C)	0.85
Absorbers (below –18 °C)	0.80
Amine Contactor	0.80
Vacuum Towers	0.85
Amine Stills (Amine Regenerator)	0.85
H_2S Stripper	0.85
Furfural Fractionator	0.85
Glycol Contactors	0.50
Glycol Stills	0.65
CO_2 Absorber	0.80
CO_2 Regenerator	0.85
Caustic Wash	0.65
Caustic Regenerator, Foul Water, Sour Water Stripper	0.60
Alcohol Synthesis Absorber	0.35
Hot Carbonate Contactor	0.85
Hot Carbonate Regenerator	0.90
Oil Reclaimer,	0.70

The capacity of a given tray design used in *high pressure fractionation service* with a vapor density of 28.8 kg/m^3 and higher should be derated by a system factor calculated by the following formula:

$$\text{System factor} = \frac{2.93}{(\rho_v)^{0.32}}$$

Solution Steps:

1. Enter left side of Fig. 20-25 at 4200 kPa (abs) and proceed to the H_2S concentration line (4.18 mol%)
2. Proceed vertically to the relative density of the gas (γ = 0.682)
3. Follow the diagonal guide line to the temperature at the bottom of the graph (T = 17.5 °C)
4. Apply the C_3 correction using the insert at the upper left. Enter the left hand side at the H_2S concentration and proceed to the C_3 concentration line (0.67%). Proceed down vertically to the system pressure and read the correction on the left hand scale (–1.5 °C)

Note: The C_3 temperature correction is negative when on the left hand side of the graph and positive on the right hand side.

T_H = 17.5 – 1.5 = 16 °C

Fig. 20-25 was developed based on calculated hydrate conditions using the Peng-Robinson EOS. It has proven quite accurate when compared to the limited amount of experimental data available. It should only be extrapolated beyond the experimental data base with caution.

Fig. 20-26[34] presents experimental hydrate formation data for three mixtures of methane, propane and hydrogen sulfide. Results of selected hydrate prediction methods are also shown.

The addition of CO_2 to pure methane will slightly increase the hydrate temperature at a fixed pressure.[35] However, the addition of CO_2 to a "typical" sweet natural gas mixture will often lower the hydrate formation temperature at a fixed pressure. Fig. 20-27 is provided to portray these compositional effects. The hydrate curves for four gas compositions are shown. These were generated using a commercial hydrate program employing the Peng-Robinson EOS. The four gas compositions are:

Sweet Gas (0.6 rel. den. gas from Fig. 20-16)
Sweet Gas containing 10% CO_2
Sour Gas containing 10% H_2S
Sour Gas containing 10% CO_2 and 10% H_2S

Note that H_2S significantly increases the hydrate temperature of a sweet natural gas. In this example, at 6900 kPa (abs), the addition of H_2S (10 mol%) to a sweet gas mixture increases the hydrate temperature by 8 °C. On the other hand, CO_2 has a minor effect on the hydrate formation temperature and slightly decreases the hydrate temperature for both the "sweet" and "sour" gases in this case.

EOS-based computer programs are probably the most consistent method of predicting hydrate formation temperatures today. Accuracy when compared to experimental data is usually ± 1 °C. This is generally adequate for design.

Hydrate Inhibition

The formation of hydrates can be prevented by:

1. Maintaining the system temperature above the hydrate formation temperature by the use of a heater and/or insulation
2. Dehydrating the hydrocarbon fluid (gas and/or liquid) to eliminate the condensation of liquid or solid water
3. Injection of a chemical inhibitor to prevent or mitigate hydrate formation

In some cases, heating or dehydration may not be practical or economically feasible.

In these cases, chemical inhibition can be an effective method of preventing hydrate formation. Chemical inhibition utilizes injection of thermodynamic inhibitors (sometimes called equilibrium inhibitors) or low dosage hydrate inhibitors (LDHIs). Thermodynamic inhibitors are the traditional inhibitors (i.e., one of the glycols or methanol), which lower the temperature of hydrate formation. LDHIs are either kinetic hydrate inhibitors (KHIs) or antiagglomerants (AAs). They do not lower the temperature of hydrate formation, but do diminish its effect. KHIs lower the rate of hydrate formation, which inhibits its development for a defined duration. AAs allow the formation of hydrate crystals but restrict them to sub-millimeter size.

Thermodynamic inhibitors — Inhibition utilizes injection of one of the glycols or methanol into a process stream where it can combine with the condensed aqueous phase to lower the hydrate formation temperature at a given pressure. Both

FIG. 20-26

Experimental vs. Predicted Hydrate Conditions for Gases Containing C_1, C_3, and H_2S

Composition, mol %				Experimental Data[17]		Predicted Temperature, °C		
C_1	C_3	H_2S	γ	Temperature, °C	Pressure, kPa (abs)	Fig. 20-13	Equation 20-3	Fig. 20-25
88.654	7.172	4.174	0.649	4.6	706	NA	2.6	5.4
88.654	7.172	4.174	0.649	11	1419	5.0	8.4	11.3
88.654	7.172	4.174	0.649	14.2	2024	7.2	11.2	14.1
88.654	7.172	4.174	0.649	18	3367	11.7	14.9	18.4
81.009	7.016	11.975	0.696	10.4	817	1.1	5.1	10.8
81.009	7.016	11.975	0.696	19.5	2813	11.7	14.9	21.5
60.888	7.402	31.71	0.823	13.1	686	2.8	7.1	13.2
60.888	7.402	31.71	0.823	19.1	1445	8.3	15.3	20.3
60.888	7.402	31.71	0.823	24.3	2558	12.8	19.7	24.8
60.888	7.402	31.71	0.823	27.8	4275	16.7	24.1	28.7

glycol and methanol can be recovered with the aqueous phase, regenerated and reinjected. For continuous injection in services down to –40 °C, one of the glycols usually offers an economic advantage versus methanol recovered by distillation. At cryogenic conditions (below –40 °C) methanol usually is preferred because glycol's viscosity makes effective separation difficult.

Ethylene glycol (EG), diethylene glycol (DEG), and triethylene glycol (TEG) have been used for hydrate inhibition. The most popular has been ethylene glycol because of its lower cost, lower viscosity, and lower solubility in liquid hydrocarbons.

Physical properties of methanol and methanol-water mixtures are given in Fig. 20-28 through Fig. 20-31. Physical properties of the most common glycols and glycol-water mixtures are given in Fig. 20-32 through Fig. 20-49. Tabular information for the pure glycols and methanol is provided in Fig. 20-50.

Equilibrium inhibitors are used in both pipeline/flowline applications as well as in low temperature gas processing facilities. To be effective, the inhibitor must be present at the very point where the wet gas is cooled to its hydrate temperature.

Fig. 20-51 shows a flow diagram for a typical EG injection system in a refrigeration plant. In these facilities, the glycol inhibitor is sprayed into the gas upstream of the exchanger. The exchanger type can be shell and tube, plate or printed circuit. As water condenses, the inhibitor is present to mix with the water and prevent hydrates. Injection must be in a manner to allow good distribution in the gas flow path. It is common practice to inject 2 to 3 times the glycol rate calculated from the correlations that follow.

The viscosity of ethylene glycol and its aqueous solutions increases significantly as temperature decreases. This effect must be considered in the design and rating of exchangers in low temperature gas processing facilities.

The inhibitor and condensed water mixture is separated from the gas stream along with a separate liquid hydrocarbon stream. At this point, the water dew point of the gas stream is essentially equal to or slightly lower than the separation temperature. Glycol-water solutions and liquid hydrocarbons can emulsify when agitated or when expanded from a high pressure to a lower pressure, e.g., JT expansion valve. Careful separator design normally allows nearly complete recovery of the diluted glycol for regeneration and reinjection.

The regenerator in a glycol injection system should be operated to produce a regenerated glycol solution that will have a freezing point below the minimum temperature encountered in the system. This is typically 75–80 wt%. Fig. 20-52 shows the freezing point of various concentrations of glycol water solutions.

The minimum inhibitor concentration in the free water phase may be approximated by Hammerschmidt's equation.[36]

$$d = \frac{K_H X_I}{M_I (1 - X_I)} \qquad \textbf{Eq 20-4}$$

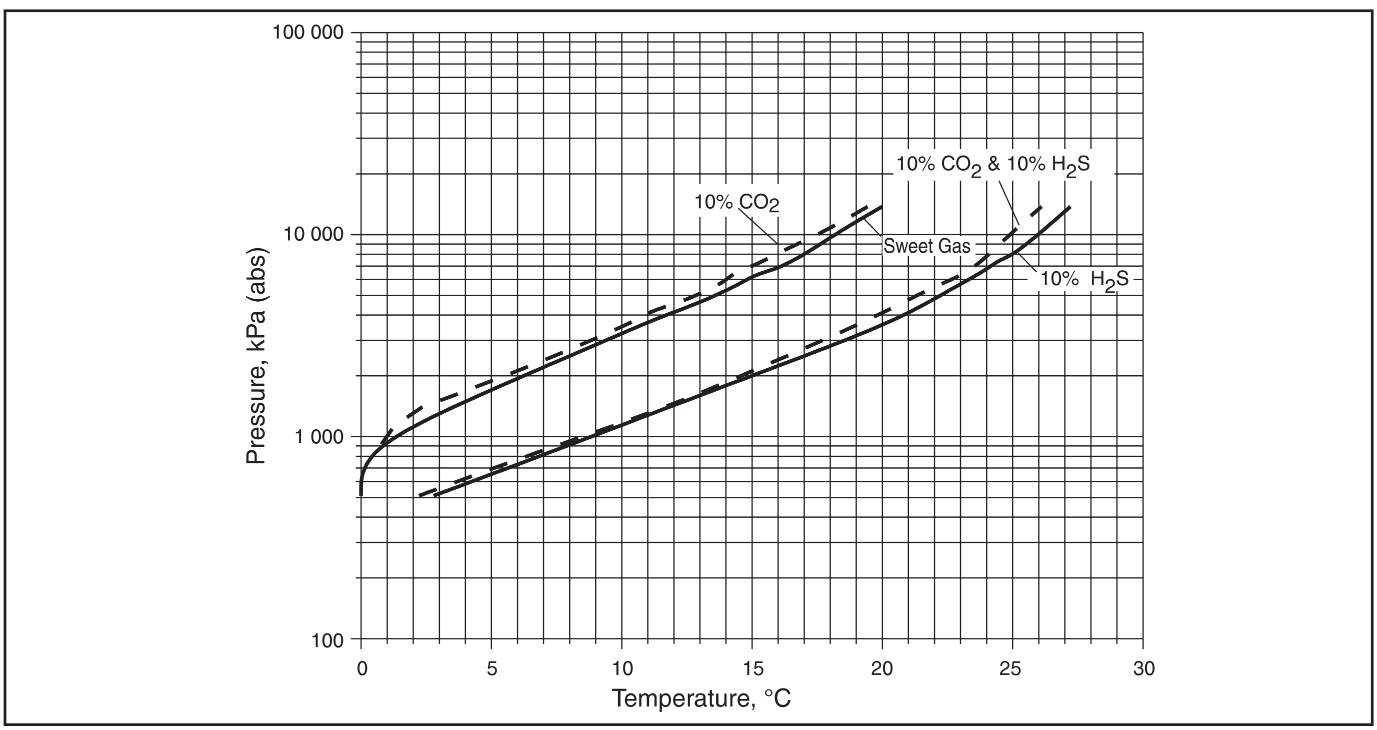
$$X_I = \frac{dM_I}{K_H + dM_I} \qquad \textbf{Eq 20-5}$$

Where K_H for ethylene glycol and methanol = 1297.

Earlier editions of the Engineering Data Book suggested a range of K_H values (1297–2222) for glycols. Higher values of K_H result in lower concentrations of rich (diluted) glycol (X_I in Equation 20-5) which, in turn, suggests a lower inhibitor injection rate. Experimental data suggests K_H = 1297 is the correct constant as illustrated in Fig. 20-53. In some field operations,

FIG. 20-27

Hydrate Formation Conditions for Sweet Gas Showing Effects of CO_2 and H_2S



Solution Steps:

Methanol

1. Calculate the amount of water condensed per day from Fig. 20-4,

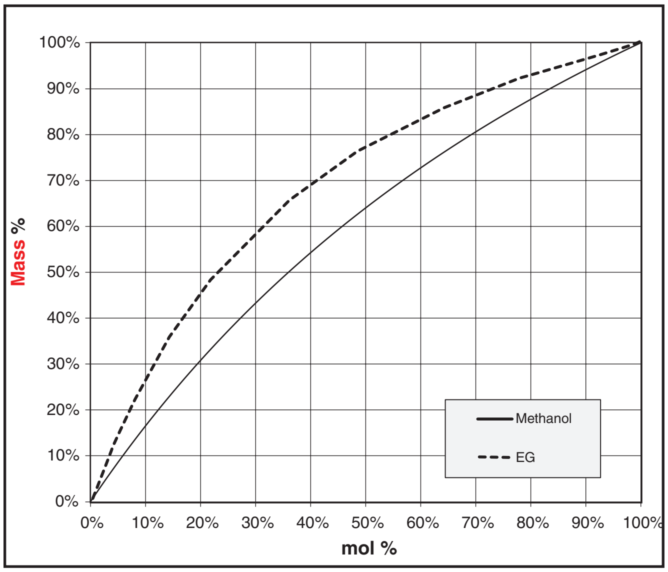
$$W_{in} = 850 \text{ kg}/10^6 \text{ Sm}^3$$
$$W_{out} = 150 \text{ kg}/10^6 \text{ Sm}^3$$
$$\Delta W = 700 \text{ kg}/10^6 \text{ Sm}^3$$

Water condensed = (700)(2.83) = 1980 kg/d

2. Calculate required methanol inhibitor concentration from Equation 20-5 and 20-6

FIG. 20-54

Mass % vs. Mol% for Methanol and EG Solutions



d = 14 °C, M = 32

Solving for X_I,

From Equation 20-5, $X_I = 0.255$,

From Equation 20-6, mol fr. = 0.175 (use this value in subsequent calculations)

From Fig. 20-54, Mass % = 27.5

3. Calculate mass rate of inhibitor in water phase from Equation 20-9 (assume 100% methanol is injected)

$$m_I = \frac{X_R \cdot m_{H_2O}}{X_L - X_R} = \frac{(0.275)(1980)}{(1 - 0.275)} = 750 \text{ kg/d}$$

4. Estimate vaporization losses from Fig. 20-55.

@ 4 °C and 6200 kPa (ga), losses = (30 kg/10^6 Sm^3)/mol% MeOH in water phase

daily losses = (30)(2.83)(17.5) = 1490 kg/d

5. Estimate losses to hydrocarbon liquid phase from Fig. 20-56.

@ 4 °C and paraffinic fluid, Dist. Ratio = 110
mol % MeOH in hyd. liquid = 17.5/110 = 0.16 mol%

1 m^3 of condensate has a mass of 780 kg

= (780/140) =5.6 kmol/m^3 of condensate

= (5.6)(0.0016) =0.009 kmol MeOH

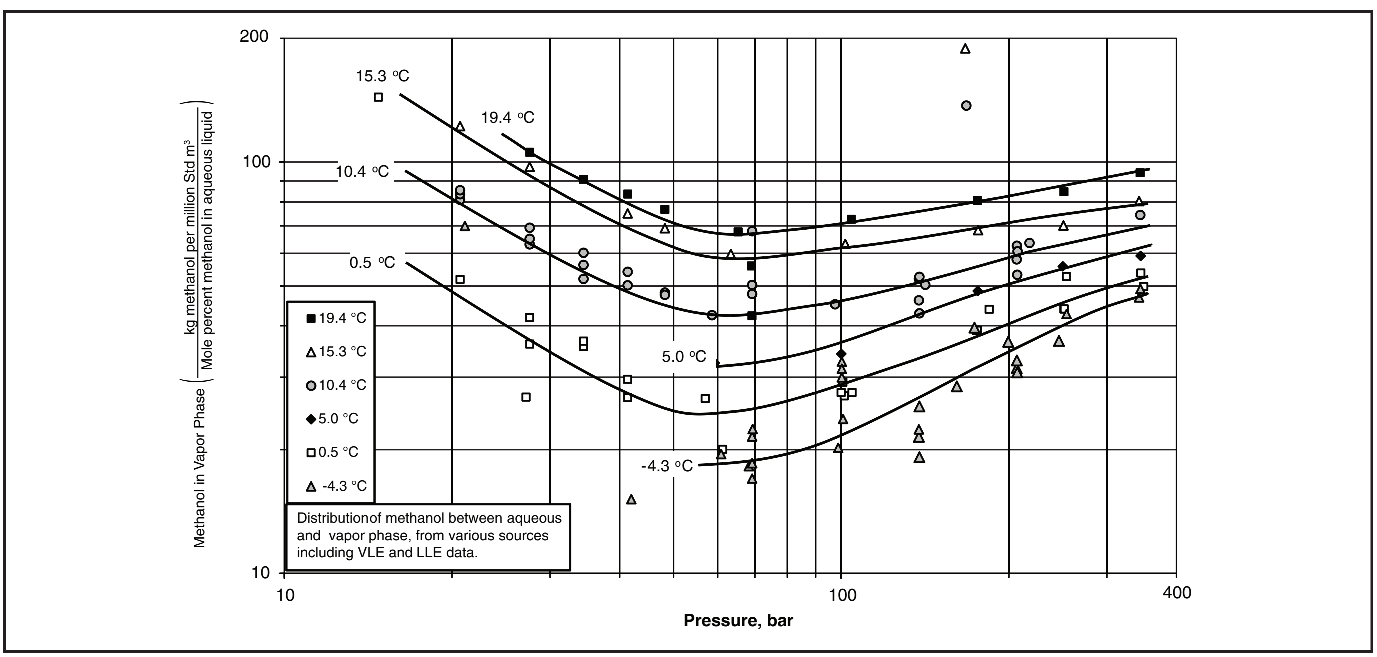
= (32)(0.009) = 0.29 kg/m^3

Total MeOH losses to the hydrocarbon liquid phase = (0.29)(2.83)(56) = 46 kg MeOH/d

Total methanol injection rate = 750 + 1490 + 46 = 2286 kg/d

FIG. 20-55

Ratio of Methanol Vapor Concentration to Methanol Liquid Concentration



Methanol left in the gas phase can be recovered by condensation with the remaining water in a downstream chilling process. Likewise, the methanol in the condensate phase can be recovered by downstream water washing.

80 wt% EG

1. Calculate required inhibitor concentration from Equation 20-5

$d = 14$ °C, $M = 62$, $K_H = 1297$

Solving for X_I, $X_I = 0.40$

2. Calculate mass rate of inhibitor solution in water phase from Equation 20-9

$$m_I = \frac{(0.40)(1980)}{(0.80 - 0.40)}$$

$$= 1980 \text{ kg/d}$$

Vaporization and liquid hydrocarbon losses are negligible.

Hydrate inhibition with methanol or EG is widely used in pipelines as well as in gas processing plants. The choice of inhibitor is influenced by several factors. A few of these are listed below:

Methanol Advantages

- Generally less expensive than EG
- Requires lower concentrations in the aqueous phase
- Can inhibit to very low temperatures
- Has a lower viscosity than EG
- During regeneration, contaminants in the water phase (such as dissolved solids) leave with the water, not the methanol
- Can be transported in the vapor phase (significant methanol vaporization at injection point) which is useful for removing hydrates that have formed downstream of the injection point in the system

Methanol Disadvantages

- Higher inhibitor losses to the hydrocarbon vapor and liquid phases
- More difficult to recover methanol from the aqueous phase
- More toxic than EG
- More flammable than EG (lower flash point)

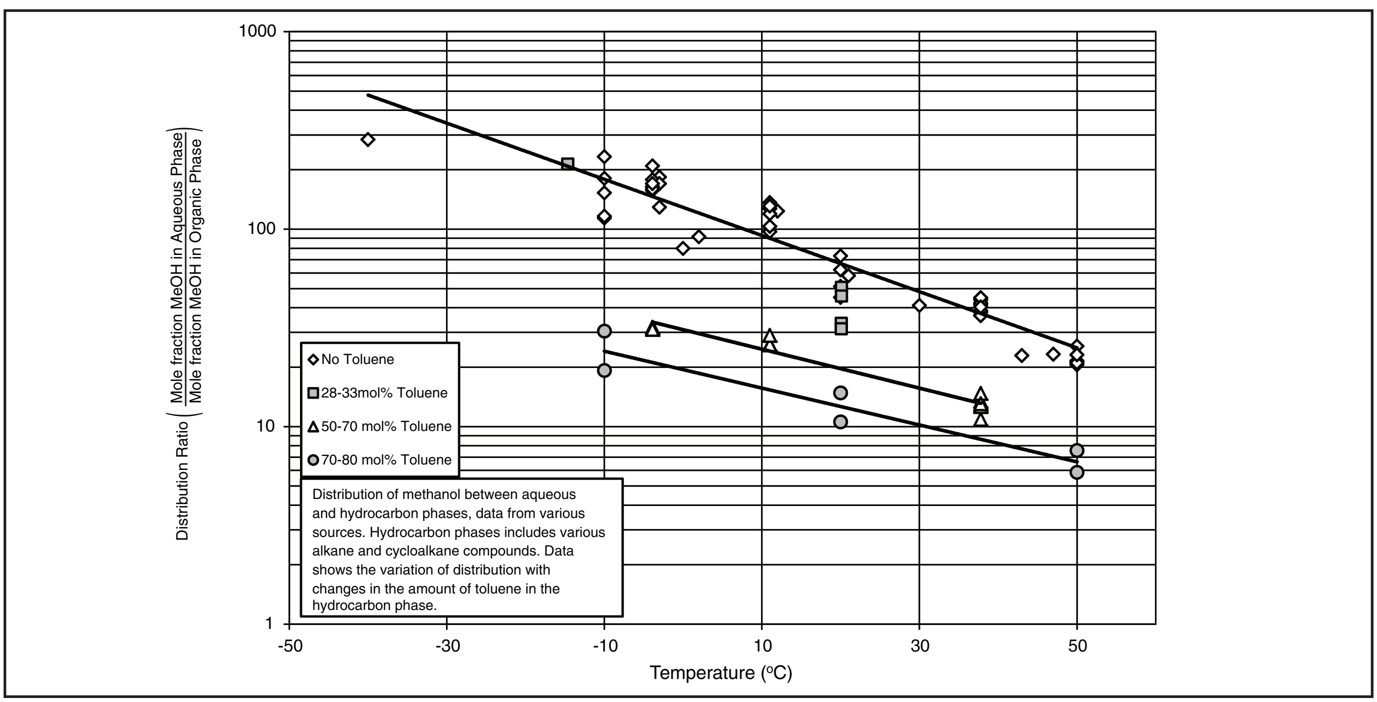
Methanol losses to the hydrocarbon vapor and liquid phases has become a more significant issue due to increasingly stringent contaminant specifications for condensate, NGLs and natural gas.

EG Advantages

- Very low solubility losses to the hydrocarbon phases and generally not regarded as a contaminant
- Much easier to recover from the water phase (regeneration)
- Less toxic and less flammable than methanol
- Can also provide corrosion inhibition for "top of the line corrosion" in pipelines

FIG. 20-56

Liquid-Liquid Methanol Distribution Ratios



$$Q_w = \left[4200 \frac{kJ}{kg}\right] (\text{kg of water on bed}) \qquad \textbf{Eq 20-22}$$

$$Q_{si} = (\text{kg of sieve}) \left[\frac{1.0\ kJ}{kg \cdot K}\right] (T_{rg} - T_i) \qquad \textbf{Eq 20-23}$$

$$Q_{st} = (\text{kg of steel}) \left[\frac{0.5\ kJ}{kg \cdot K}\right] (T_{rg} - T_i) \qquad \textbf{Eq 20-24}$$

$$Q_{hl} = (\text{heat loss}) = Q_w + Q_{si} + Q_{st})(0.10) \qquad \textbf{Eq 20-25}$$

The temperature, T_{rg}, is the temperature to which the bed and vessel must be heated based on the vessel being externally insulated (i.e., no internal insulation which is usually the case). This is about 28 °C below the temperature of the hot regeneration gas entering the tower.

The weight of the vessel steel is estimated from the equations below. Equation 20-25 is the ASME Section VIII Div. 1 equation in terms of the vessel inside diameter. It is based on a maximum tensile stress of 130 MPa (i.e., the ASME 2001 maximum allowable tensile stress for SA516 Grade 70 steel at 343 °C and a welded-joint efficiency of 1.0). This is 134 MPa at 315 °C. The design pressure, P_{design}, is usually set at 110% of the maximum operating pressure. The value of 3.2 mm in Equation 20-26 is the corrosion allowance in inches. The term $0.75D_{bed}$ accounts for the weight of the tower heads. The value of 0.91 mm provides the space for the inlet distributor and support and hold-down balls.

$$t(mm) = (1000\ D_{bed}P_{design}) / ((2x130{,}000 = 260{,}000\ kPa) - 1.2P_{design}) \qquad \textbf{Eq 20-26}$$

$$\text{Mass of steel (kg)} = 29.8\ (t + 3.2)(L_S + L_{MTZ} + 0.75\ D_{bed} + 0.91)D_{bed} \qquad \textbf{Eq 20-27}$$

For determination of the regeneration gas rate, calculate the total regeneration load from Equation 20-28.

$$Q_{tr} = (2.5)(Q_w + Q_{si} + Q_{st} + Q_{hl}) \qquad \textbf{Eq 20-28}$$

The 2.5 factor corrects for the change in temperature difference (in – out) across the bed with time during the heating period. It assumes that 40% of the heat in the regeneration gas transfers to the bed, vessel steel, and heat loss to atmosphere; and the balance leaves with the hot gas.

The regeneration-gas flow rate is calculated from Equation 20-29 below. A typical average heat capacity for regeneration gas is 2.7 kJ/kg °C. The temperature, T_{hot}, is 28 °C above the temperature, T_{rg}, to which the bed must be heated. The temperature, T_b, is the bed temperature at the beginning of regeneration, which is the same as the dehydration-plant feed temperature.

The heating time is usually 50% to 60% of the total regeneration time which must include a cooling period. Fig. 20-83 shows a typical temperature profile for a regeneration period (heating and cooling). For 8 hour adsorption periods, the regeneration normally consists of 4 1/2 hours of heating, 3 hours of cooling and 1/2 hour for standby and switching. For longer periods the heating time can be lengthened as long as a minimum pressure drop of 0.23 kPa/m is maintained to ensure even flow distribution across the bed.

$$\dot{m}_{rg} = Q_{tr}/(C_p(T_{hot} - T_b)\ (\text{heating time})) \qquad \textbf{Eq 20-29}$$

The superficial velocity of the regeneration gas is calculated from Equation 20-30 for which q is calculated from Equation 20-16.

$$V = \frac{4q}{(\pi D^2)} \qquad \textbf{Eq 20-30}$$

The calculated superficial velocity can not be less than the value that corresponds with a minimum bed pressure drop of 0.23 kPa/m. This can be determined from Fig. 20-84, which was derived from Equation 20-14 by assuming a gas composition and temperature and setting $\Delta P/L$ equal to 0.23 kPa/m. If the calculated velocity is less than this, the regeneration gas rate, $\dot{m}_{rg}$, must be increased by multiplying it by the ratio V_{min}/V, and the period of regeneration should be decreased by multiplying it times the ratio V/V_{min}. Equation 20-14 may also be used to calculate V_{min} using a $\Delta P/L$ equal to 0.23 kPa/m.

FIG. 20-83

Inlet and Outlet Temperatures During Typical Solid Desiccant Bed Regeneration Period

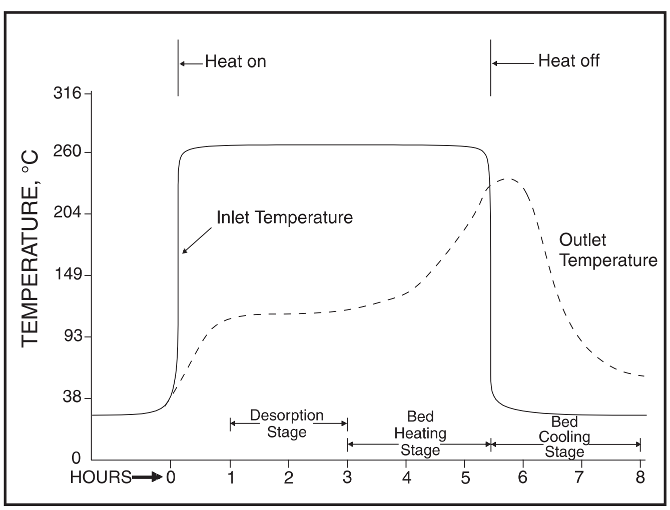
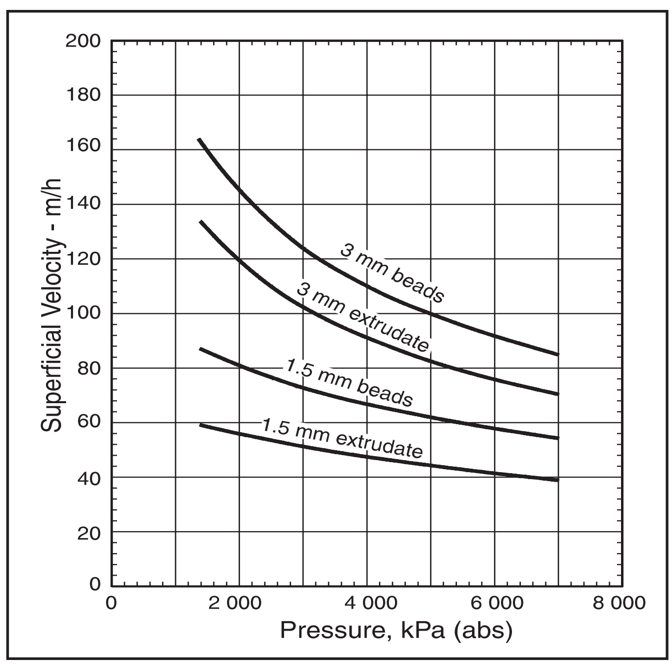


FIG. 20-84

Minimum Regeneration Velocity for Mole Sieve Dehydrator



General Comments

The regeneration cycle frequently includes depressuring/repressuring to match the regeneration gas pressure and/or to maximize the regeneration gas volume to meet the velocity criterion. In these applications, the rate of depressuring or repressuring should not exceed 350 kPa per/minute. Some applications, termed pressure swing adsorption, regenerate the bed only with depressurization and sweeping the bed with gas just above atmospheric pressure, but this is not used in gas dehydration applications.

Moisture analyzers for very low water contents require care to prevent damage to the probes. When inserted into the beds, sample probes and temperature probes must be installed to reach the center of the gas phase.

Solid desiccant towers are insulated externally or possibly internally. Internal refractory requires careful installation and curing, usually before the desiccant is installed. It saves energy but the greatest benefit is it can dramatically reduce the required heating and cooling times. This is often an important benefit for systems where regeneration times are limited. The primary disadvantage is the potential for wet gas bypassing the desiccant through cracks and defects in the insulation during the adsorption cycle.

Example 20-14: 2.85×10^6 Sm^3/day of natural gas with a molecular weight of 18 is to be processed for ethane recovery in a turbo-expander plant. It is water saturated at 4140 kPa (abs) and 38 °C and must be dried to –101 °C dew point. Determine the water content of the gas, and the amount of water that must be removed; and do a preliminary design of a molecular-sieve dehydration system consisting of two towers with down-flow adsorption in one tower and up-flow regeneration in the other. Use 4A molecular sieve of 3.2 mm beads (i.e., 4x8 mesh). The regeneration gas is part of the plant's residue gas, which is at 4140 kPa (abs) and 38 °C and has a molecular weight of 17. The bed must be heated to 260 °C for regeneration.

Solution Steps

1. Determine the bed diameter and the corresponding $\Delta P/L$ and V. First determine the maximum superficial velocity from Equation 20-14. Let the maximum $\Delta P/L$ be 7.5 kPa/m.

   z = 0.93 from Fig. 23-8 for 17.4 mole weight which is conservative

   ρ = (18 mole weight) (4140 kPa (abs))/((8.3145) (311.15 °K) (0.93)) = 31 kg/m^3 (Equation 23-2)

   μ = 0.015 mPa · s (Fig. 23-27)

   $V_{max} = [(7.5\ kPa/m)/(3.75 \cdot 10^{-7})/(31\ kg/m^3)]^{1/2} - [(0.0693/3.75 \cdot 10^{-7})\ (0.015\ mPa\ s)/(31\ kg/m^3)/2]$ = 758 m/h (Equation 20-14), rewritten in terms of V

   $\dot{m} = [(2.85 \cdot 10^6\ Sm^3/day)/((24\ h/day)(23.646\ Sm^3kmole))]\ (18\ kg/kmole)$ = 90 400 kg/h

   q = (90 400 kg/h)/(31 kg/m^3) = 2916 m^3/h (Equation 20-16)

   $D_{minimum} = [(4(2916\ m3/h))/(\pi \cdot 758\ m/h)]^{1/2}$ = 2.21 m (Equation 20-15)

Round off upward to 2.25 m diameter, for which V and $\Delta P/L$ are adjusted as follows:

$V_{adjusted} = (758\ m/h)(2.21/2.25)^2$ = 731 m/h (Equation 20-17)

$(\Delta P/L)_{adjusted} = 7.5(731/758)^2$ = 7.0 kPa/m (Equation 20-21)

2. Estimate the amount of water to be removed from the feed per cycle for each bed. Base this on a 24-hour cycle consisting of 12 hours adsorbing and 12 hours regenerating (heating, cooling, standby, and valve switching). From Fig. 20-4, the water content at 4140 kPa (abs) and 38 °C is 1410 mg/Sm^3 (1410 kg/10^6 Sm^3). The water content at a dew point of –101 °C is essentially zero, so the water removed is the following:

   $\dot{w} = (1410\ kg/10^6\ Sm^3)(2.85\ 10^6\ Sm^3/day)/(24\ h/day)/$ = 167 kg/h of water removed

   W_r = (167 kg/h) (12 h) = 2004 kg water removed per 12-hour drying period or 24-hour cycle per bed.

3. Determine the amount of sieve required and the bed height based on a sieve bulk density of 720 kg/m^3. Since the feed gas is water saturated, the relative humidity is 100%, so C_{SS} is 1.0 from Fig. 20-81. From Fig. 20-82, C_T is 0.93 at 38 °C. Applying the equations:

   S_S = (2004)/((0.13)(1.0)(0.93)) = 16 576 kg of sieve for each bed (Equation 20-18)

   $L_S = (16\ 576)(4)/(3.1416\ (2.3)^2\ (720))$ = 5.54 m bed height (Equation 20-19)

   $L_{MTZ} = (731/640)^{0.3}\ (0.52)$ = 0.54 m for mass-transfer zone (Equation 20-20)

   $L_S + L_{MTZ}$ = 5.54 + 0.54 = 6.08 m of sieve for each bed

   The total sieve = (6.08/5.54)(16 576) = 18 192 kg for each bed

4. Check the bed design and pressure drop which is the $\Delta P/L$ calculated in Step 1 times the total bed height calculated in Step 3: (7.0 kPa/m)(6.08 m) = 42.6 kPa which meets the criteron of not exceeding 35–55 kPa

5. Calculate the total heat required to desorb the water based on heating the bed and vessel to 260 °C. First calculate the weight of steel from Equation 20-26 and 20-27. Let the design pressure, P_{design}, be 110% of the operating pressure:

   P_{design} = (4140)(1.1) = 4554 kPa (ga)

   $$t = \frac{(1000)\ (2.25)\ (4554)}{260\ 000 - 1.2\ (4554)} = 40.3\text{ mm (Equation 20-26)}$$

   Mass of steel = (29.8) (40.3 + 3.2) (5.54 + 0.54 + (0.75) (2.25) + 0.91) (2.25) = 25 310 kg (Equation 20-27)

   Q_{st} = (25 310 kg) (0.5 kJ/kg °C) (260 °C – 38 °C) = 2 809 000 kJ (Equation 20-24)

   Q_w = (4200 kJ/kg) (2004 kg water) = 8 417 000 kJ (Equation 20-22)

   Q_{si} = (18 192 kg) (1 kJ/kg °C) (260 °C – 38 °C) = 4 039 000 kJ (Equation 20-23)

   Q_{hl} = (2 809 000 + 8 417 000 + 4 039 000) (0.10) = 1 527 000 kJ (Equation 20-25)

   Q_{tr} = (2.5) (2 809 000 + 8 417 000 + 4 039 000 + 1 527 000) = 41 980 000 kJ (Equation 20-28)

15–20% for MEA (more moles of amine per volume of solution).

- The required treating circulation rate is lower. This is a direct function of higher amine concentration.
- Reduced reboiler steam consumption.

Typical concentrations of DGA® range from 50% to 60% DGA® by weight while in some cases as high as 70 wt% has been used. DGA® has an advantage for plants operating in cold climates where freezing of the solution could occur. The freezing point for 50% DGA® solution is –34 °C. Because of the high amine degradation rate DGA® systems require reclaiming to remove the degradation product. DGA® reacts with both CO_2 and COS to form N, N', bis (hydroxyethoxyethyl) urea, generally referred to as BHEEU.[16] DGA® is recovered by reversing the BHEEU reaction in the reclaimer.

Methyldiethanolamine—Methyldiethanolamine (MDEA) is a tertiary amine which can be used to selectively remove H_2S to pipeline specifications at moderate to high pressure. If increased concentration of CO_2 in the residue gas does cause a problem with contract specifications or downstream processng, further treatment will be required. The H_2S/CO_2 ratio in the acid gas can be 10–15 times as great as the H_2S/CO_2 ratio in the sour gas. Some of the benefits of selective removal of H_2S include:

- Reduced solution flow rates resulting from a reduction in the amount of acid gas removed
- Smaller amine regeneration unit
- Higher H_2S concentrations in the acid gas resulting in reduced problems in sulfur recovery

CO_2 hydrolyzes much slower than H_2S. This makes possible significant selectivity of tertiary amines for H_2S. This fact is used by several companies who provide process designs using MDEA for selective removal of H_2S from gases containing both H_2S and CO_2.

A feature of MDEA is that it can be partially regenerated in a simple flash. As a consequence the removal of bulk H_2S and CO_2 may be achieved with a modest heat input for regeneraion. However as MDEA solutions react only slowly with CO_2 (see chemistry) activators must be added to the MDEA soluion to enhance CO_2 absorption. If this is done, then the solvent is referred to as promoted or activated MDEA.

Triethanolamine — Triethanolamine (TEA) is a tertiary amine and has exhibited selectivity for H_2S over CO_2 at low pressures. TEA was the first amine commercially used for gas sweetening. It was replaced by MEA and DEA because of its inability to remove H_2S and CO_2 to low outlet specifications. TEA has potential for the bulk removal of CO_2 from gas streams. It has been used in many ammonia plants for CO_2 removal.

Diisopropanolamine — Diisopropanolamine (DIPA) is a secondary amine which exhibits, though not as great as tertiary amines, selectivity for H_2S. This selectivity is attributed to the steric hindrance of the chemical. (See later discussion on this topic.)

Formulated solvents and mixed amines — Formulated Solvents is the name given to a new family of amine-based solvents. Their popularity is primarily due to equipment size reduction, reduced corrosion and energy savings over most of the other amines.

All the advantages of MDEA are valid for the Formulated Solvents, usually to a greater degree. Some formulations are capable at high pressure of slipping larger portions of inlet CO_2 than generic MDEA to the outlet gas and at the same time removing H_2S to less than 4 ppmv. Under conditions of low absorber pressure and high CO_2 /H_2S ratios, such as Claus tail gas clean-up units, certain solvent formulations can slip up to 90% of the incoming CO_2 to the incinerator.

At the other extreme, certain formulations remove CO_2 to a level not possible with MDEA, so that the sweet gas is suitable for cryogenic plant feed. Formulations are also available for CO_2 removal in ammonia plants. Finally, there are solvent formulations, which remove H_2S to 4 ppmv pipeline specifications, while reducing high inlet CO_2 concentrations to 2% for delivery to a pipeline. Typical treating applications for the gas processing industry, and the common treatment strategies employed using formulated amines, are summarized in Fig. 21-12. Several general approaches are commonly used in the solvent formulations.

To achieve very low CO_2 concentrations in the treated gas, the formulation may contain activators, such as piperazine or primary/secondary amines to promote CO_2 removal.

In order to enhance H_2S removal, and thereby allow greater CO_2 slip, stripping agents, such as inorganic acids may be used.

This need for a wide performance spectrum has led Formulated Solvent suppliers to develop a large stable of different MDEA-based solvent formulations or MDEA-based solvents. In summary, benefits claimed by suppliers are:

For New Plants

- reduced corrosion
- reduced circulation rate
- lower energy requirements
- smaller equipment due to reduced circulation rates

For Existing Plants

- increase in capacity, i.e., gas through-put or higher inlet acid gas composition
- reduced corrosion
- lower energy requirements and reduced circulation rates

Formulated solvents are proprietary to the specific supplier offering the product. Companies offering these products and/or processes include INEOS, Huntsman Corporation, Dow Chemical Company, UOP, BASF, Shell Global Solutions and Total via Prosernat.

FIG. 21-12

Common Formulated Amines Applications

Treating Strategy	Gas Treating Specification/Application
Deep H_2S and CO_2 removal	Outlet H_2S (4 PPM) & CO_2 (down to <50 ppmv)/Treating high pressure sour gas w/ H_2S for downstream cryogenic processing
Deep CO_2 removal w/some CO_2 slip	Outlet H_2S (4 ppmv) & CO_2 (0.5 to 2 mol%)/ Treating high pressure sour gas w/H_2S to pipeline specifications
Deep CO_2 Removal	Outlet CO_2 down to <50 ppmv/Treating high pressure gas w/CO_2 upstream of cryogenic processing
CO_2 removal with slip	Outlet CO_2 (2 mol%)/Treating high pressure gas w/CO_2 to pipeline specifications
Deep CO_2 removal with bypass	Outlet CO_2 (100–1000 ppmv)/Treating high pressure gas to produce pipeline quality gas (2 mol% CO_2) using feed gas bypass
Deep H_2S removal with high CO_2 slip	Outlet H_2S (10 ppmv to 250 ppmv) w/high CO_2 slip/Sulfur plant tail gas treating applications
Deep H_2S removal with high CO_2 slip	Outlet H_2S (50 ppmv to 250 ppmv) w/high CO_2 slip/Acid gas enrichment for Claus sulfur plant feed

Sterically hindered amines — Other amines have been used to treat sour gas.[17] One specialty amine uses steric hindrance (see nomenclature) to slow the rate of CO_2 absorption. This type of amine and the associated technology is different than Formulated Solvents, which create the desired formulations by blending different components with a standard amine such as MDEA. These sterically hindered amines are very selective for the removal of H_2S in the presence of CO_2. For low pressure applications such as AGE and TGCU, the CO_2 slip can be as high as 95%. An example of this technology is FLEXSORB®SE/SE Plus solvents, marketed by ExxonMobil Research and Engineering Company.[18,19]

Acid Gas Enrichment

Normally, Acid Gas Removal units (AGRs) remove essentially all of the H_2S and CO_2 from the produced natural gas. As discussed previously, AGRs can utilize a variety of solvents, including generic and formulated MDEA. In some cases, controlled CO_2 removal can be used using a selective solvent such as FLEXSORB®SE or an MDEA based solvent to leave some of the CO_2 in the sales gas. However, for gas fields with high CO_2 to H_2S ratios, the acid gas stream from the AGR regenerator will have an unfavorably high CO_2 to H_2S ratio resulting in a poor quality feed to a Claus plant.

In the last few decades, Acid Gas Enrichment (AGE) has been used much more frequently to increase the H_2S content in high CO_2 containing acid gas streams. As the name implies, acid gas enrichment concentrates the H_2S from the AGR system by further gas treatment in a second amine unit utilizing a selective amine solvent. Except for the use of the selective amine solvent, an AGE unit is similar to other traditional amine treating units. Fig. 21-13 shows a simplified flow diagram of an acid gas enrichment unit. The AGR acid gas is fed to the base of an absorber column equipped with either trays or packing where the H_2S is absorbed via counter-current contacting with the descending amine solvent. The AGE absorber typically operates at low pressure [~0.5 barg, 48 kPa (ga)], compatible with the operating pressure of the upstream AGR regenerator overhead system, but generally somewhat higher to provide the required inlet pressure to the SRU, so that the main AGR doesn't need to provide the extra pressure drop. The selective amine in the AGE preferentially absorbs the H_2S and allows the CO_2 to remain in the treated gas (also known as "CO_2 slip"). The rich amine from the bottom of the absorber is then pumped through a rich-lean heat exchanger and on to a regenerator tower. The regenerator produces an enriched acid gas product overhead and the lean amine bottoms product to be recycled to the absorber.

To achieve the twin goals of low H_2S in the treated gas and low CO_2 in the enriched acid gas, the AGE amine solvent must maximize the selectivity for absorbing H_2S. Unfortunately, the CO_2 and H_2S partial pressure driving forces in the AGE absorber work against achieving these goals simultaneously.[20] As the gas moves up the absorber tower, the H_2S partial pressure is decreasing reducing the mass transfer driving force. At the same time, the CO_2 partial pressure is increasing, making CO_2 pick-up more difficult to avoid, so the concentration factor achieved in each acid gas enrichment step is limited.

Simplified design calculations — A simplified procedure for making rough estimates of the principal parameters for conventional MEA, DEA, DGA®, and MDEA amine treating facilities when both H_2S and CO_2 are present in the gas is given below. It is based on excerpts from Jones and Pearce,[21] modified and extended by the Section 21 Subcommittee[22] in 2002. The procedure involves estimating the amine circulation rate and using it as the principal variable in estimating other parameters. For estimating amine circulation rate, the following equations are suggested:

For MEA:

$$m^3/hr = 327 \bullet (Qy/x) \qquad \textbf{Eq 21-6}$$

0.33 mol acid gas pick-up per mole MEA assumed)
For DEA (conventional):

$$m^3/hr = 361 \bullet (Qy/x) \qquad \textbf{Eq 21-7}$$

(0.5 mol acid gas pick-up per mole DEA assumed)
For DEA (high loading):

$$m^3/hr = 256 \bullet (Qy/x) \qquad \textbf{Eq 21-8}$$

(0.7 mol acid gas pick-up per mole DEA assumed)
For DGA®

$$m^3/hr = 448 \bullet (Qy/x) \qquad \textbf{Eq 21-9}$$

(0.39 mol acid gas pick-up per mole DGA assumed)
For activated MDEA (assuming 9:1 ratio of MDEA to DEA)

$$m^3/hr = 415 \bullet (Qy/x) \qquad \textbf{Eq 21-9a}$$

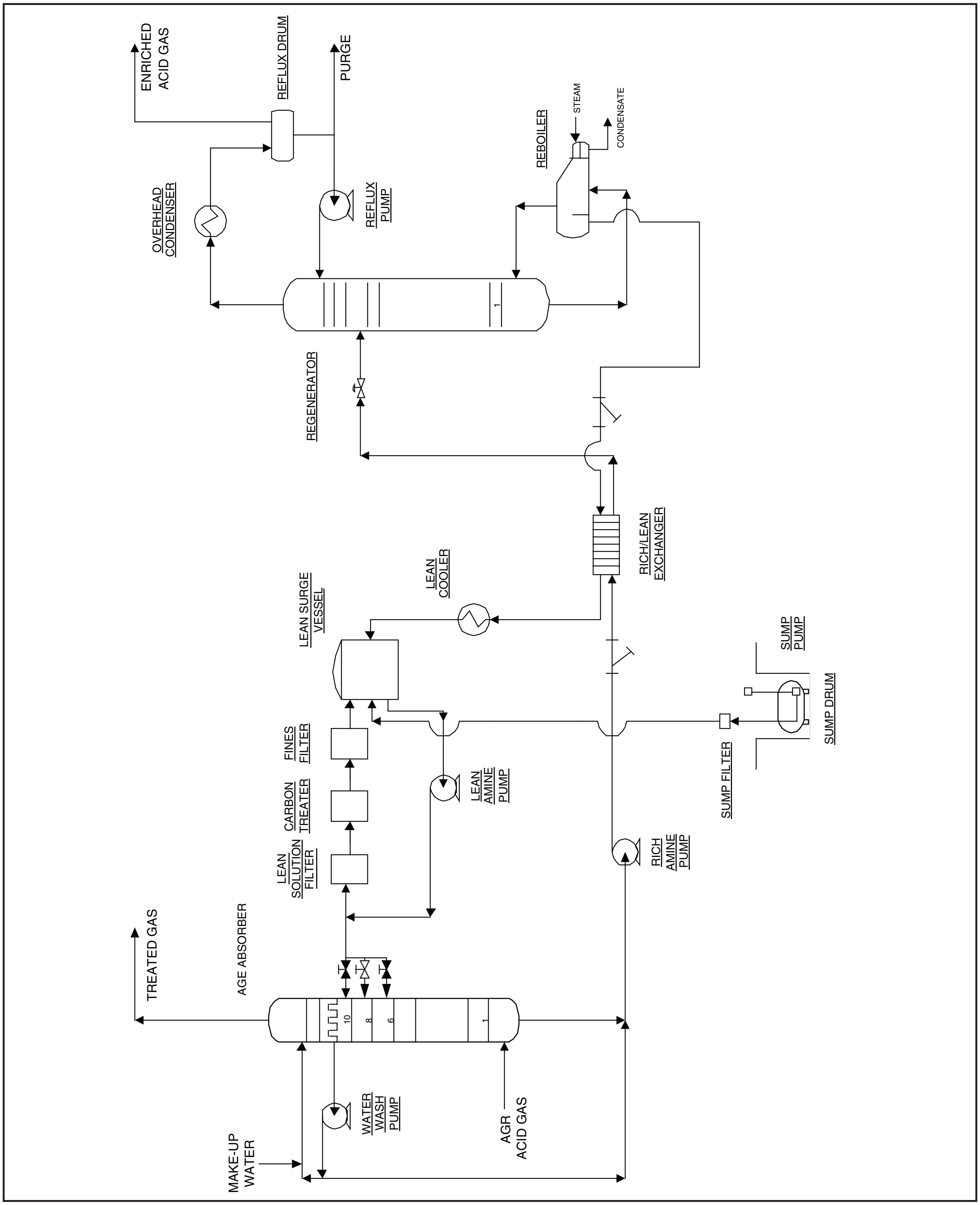
(0.50 mol acid gas pick-up per mole mixture assumed)

Where:

Q = Millions of cubic meters of sour gas to be processed, MSm^3/day
y = Acid gas concentration in sour gas, mole%
x = Amine concentration in liquid solution, wt% (Use Fig. 21-4 to ensure amine concentration does not exceed maximum recommended concentration)

After the amine circulation has been estimated, heat and heat exchange requirements can be estimated from the infor-

FIG. 21-13
Standalone AGE Flow Diagram



mation in Fig. 21-14. Pump power requirements can be estimated from Fig. 21-15.

Equations 21-6 to 21-9 normally provide conservative (high) estimates of required circulation rate. They should not be used if the combined H_2S plus CO_2 concentration in the gas is above 5 mole%. They also are limited to a maximum amine concentration of about 30% by mass.

The diameter of an amine plant contactor, can be estimated using the following equation:

Contactor diameter

$$D_c = 10\,800 \cdot \sqrt{Q / \sqrt{P}} \qquad \textbf{Eq 21-10}$$

Where:

Q = MSm³/day gas to contactor

P = Contactor pressure in kPa (abs)

D_c = Contactor diameter in mm before rounding up to nearest 150 mm.

Similarly, the diameter of the regenerator below the feed point can be estimated using the following equation:

$$D_r = 160 \cdot \sqrt{m^3/hr} \qquad \textbf{Eq 21-11}$$

Where:

m^3/h = Amine circulation rate in m^3 per hour

D_r = Regenerator bottom diameter in mm

The diameter of the section of the still above the feed point can be estimated at 0.67 times the bottom diameter.

Example 21-2 — 1.0 MSm³/day of gas available at 5860 kPa (ga) and containing 0.6% H_2S and 2.8% CO_2 is to be sweetened using 20%, by mass, DEA solution. If a conventional DEA system is to be used, what amine circulation rate is required, and what will be the principal parameters for the DEA treating system?

Solution:

Using Equation 21-7, the required solution circulation is:

$$\text{Flow } (m^3/h) = 361 \cdot (Qy/x) = 361 \cdot (1.0 \cdot 3.4/20)$$
$$= 61.4 \ m^3/h \text{ of 20\% DEA solution per minute.}$$

Heat exchange requirements (from Fig. 21-14)

Reboiler

$H = 93 \cdot 61.4 = 5710$ kW

$A = 4.63 \cdot 61.4 = 284$ m²

Rich-Lean amine exchanger

$H = 58 \cdot 61.4 = 3560$ kW

$A = 4.6 \cdot 61.4 = 282$ m²

Amine cooler

$H = 19.3 \cdot 61.4 = 1185$ kW

$A = 4.18 \cdot 61.4 = 257$ m²

Reflux condenser

$H = 38.6 \cdot 61.4 = 2370$ kW

$A = 2.13 \cdot 61.4 = 131$ m²

Power requirements (Fig. 21-15)

Main amine pumps

Power (kW) = $61.4 \cdot 5860 \cdot 0.00031 = 112$

Amine booster pumps

Power (kW) = $61.4 \cdot 0.2 = 12.3$

Reflux pumps

Power (kW) = $61.4 \cdot 0.2 = 12.3$

Aerial cooler

Power (kW) = $61.4 \cdot 1.2 = 74$

Contactor diameter

$D_c = 10\,800 \cdot \sqrt{1.0/\sqrt{5860}}$ = 1230 mm or 1350 mm rounded up

Regenerator diameter below feed point:

$D_r = 160 \cdot \sqrt{61.4}$ = 1254 mm or 1350 mm (bottom) rounded up

Regenerator diameter above feed point:

$D_{ra} = 0.67 \cdot 1254$ = 840 mm or 900 mm (top) rounded up

EQUILIBRIUM DATA FOR AMINE-SOUR GAS SYSTEMS

One of the peculiarities of amine treating systems is the interactive effects of one acid gas constituent with amine upon the equilibrium partial pressure of the other constituent. The most commonly encountered sour gas constituents are H_2S and CO_2. The capacity of a given amine for either one of the acid gas constituents alone is much greater than when the two occur together.

Jones et al.[23] have presented data to confirm the interactive effect of H_2S and CO_2 in MEA solutions. Lee et al.[12,24] have presented similar data for DEA solutions. Dingman et al.[25] have

FIG. 21-14

Estimated Heat Exchange Requirements

	Duty, kW	Area, m²
Reboiler (Direct fired)	93 · m³/h	4.63 · m³/h
Rich-Lean Amine HEX	58 · m³/h	4.60 · m³/h
Amine cooler (air cooled)	19.3 · m³/h	4.18 · m³/h
Reflux condenser	38.6 · m³/h	2.13 · m³/h

FIG. 21-15

Estimated Power Requirements

Main Amine Solution Pumps	m³/h · kPa(ga) · 0.00031	= kW
Amine Booster Pumps	m³/h · 0.20	= kW
Reflux Pumps	m³/h · 0.20	= kW
Aerial Cooler	m³/h · 1.20	= kW

Heat in, kJ/h:

Feed Gas		=	328 623
Combustion Air		=	840 534
H_2S Combustion	(42.02 kmols/h) (517 900)	=	22 797 958
HC Combustion	(2.14 kmols/h) (802 800)	=	1 717 982
Claus Reaction	(61.36/2 kmols/h) (–47 060)	=	–1 443 623
			24 241 485

The flame temperature is approximately 1164 °C.

Step 2 Waste Heat Boiler Duty

Assume that 1723 kPa (ga) steam is generated in the waste heat boiler and therefore that the temperature of the cooled combustion products is 371 °C. From Fig. 22-21 (ignoring S_7), the distribution of sulfur vapor species at 371 °C is approximately 0.5 mol % S_2, 45 mol % S_6, and 54.5 mol % S_8. The cooled combustion product composition and waste heat boiler heat balance are therefore as follows:

	Reaction Products H @ 1164 °C		
	kmols/h	kJ/kmol	kJ/h
H_2S	26.69	50 740	1 354 116
CO_2	72.19	58 838	4 247 494
H_2O	133.09	45 998	6 122 007
SO_2	13.35	60 401	805 981
N_2	264.36	36 910	9 759 624
S_2	46.01	42 471	1 954 264
S_6	—	—	—
S_8	—	—	—
	555.69		24 241 485

	Cooled Reaction Products H @ 371 °C		
	kmols/h	kJ/kmol	kJ/h
H_2S	26.69	13 410	357 879
CO_2	72.19	15 983	1 153 836
H_2O	133.09	13 160	1 751 465
SO_2	13.34	17 009	226 961
N_2	264.36	10 989	2 905 100
S_2	0.07	12 801	833
S_6	5.86	45 359	265 695
S_8	7.09	62 889	446 143
	522.69		7 107 912

ΔH: 24 241 485 – 7 107 912 = 17 133 573 kJ/h

From Fig. 22-29

S_2 (vapor) → S_6 (vapor) (5.86) (284 900) = 1 668 817 kJ/h

From Fig. 22-29

S_2 (vapor) → S_8 (vapor) (7.09) (413 800) = 2 935 558 kJ/h

Total heat duty

17 133 573 + 1 668 817 + 2 935 558 = 20 706 133 kJ/h

Note: Partial pressure of sulfur vapor

$$= \frac{S_2 + S_6 + S_8}{\text{Total Mols}} \quad (\text{Total Pressure})$$

$$= \frac{0.07 + 5.86 + 7.09}{522.69} \quad (131.7) = 3.28 \text{ kPa}$$

From Fig. 22-22, the vapor pressure of sulfur at 371 °C is approximately 30.4 kPa, so no sulfur is condensed.

Step 3 1st Sulfur Condenser

Assume a pressure drop through the condenser of 3.44 kPa, with the process stream further cooled to 177 °C. From Fig. 22-22, the vapor pressure of sulfur at 177 °C is 0.111 kPa so the stream is below the sulfur dewpoint. From Fig. 22-21, the distribution of sulfur species is 14.5 mol % S_6 and 85.5 mol % S_8. If no condensation took place, there would be 1.74 kmols/h of S_6 and 10.26 kmols/h of S_8. [Note: (6)(1.73) + (8)(10.20) = (2)(46.01)]

Uncondensed sulfur

$$= \left[\frac{0.111}{128.15 - 0.111}\right][522.69 - (1.73 + 10.20)]$$

= 0.443 kmols/h

S_6: 0.145 (0.443) = 0.0642 kmols/h uncondensed
1.73 – 0.0642 = 1.67 kmols/h condensed
S_8: 0.853 (0.443) = 0.3779 kmols/h uncondensed
10.20 – 0.3779 = 9.82 kmols/h condensed

		Condenser Outlet Conditions H @ 177°	
	kmols/h	kJ/kmol	kJ/h
H_2S	26.69	6076	162 150
CO_2	72.19	7107	513 035
H_2O	133.09	6176	821 943
SO_2	13.34	7628	101 790
N_2	264.36	5189	1 371 719
S_2 (vapor)	—	—	—
S_6 (vapor)	1.73	20 902	36 160
S_8 (vapor)	10.20	28 867	294 442
	521.60		3 301 239

ΔH: 7 107 912 – 3 301 239 = 3 806 673 kJ/h

Fig. 22-30 ΔH:

S_6 (vapor) → S_{liq} (1.67) (418.2 • 6 • 32.04) = 134 227 kJ/h

Fig. 22-30 ΔH:

S_8 (vapor) → S_{liq} (9.82) (287.2 • 8 • 32.04) = 722 900 kJ/h

Fig. 22-29 ΔH:

S_2 (vapor) → S_6 (vapor) (0.00227) (284 900) = 650 kJ/h

Fig. 22-29 ΔH:

S_2 (vapor) → S_8 (vapor) (0.014 065) (413 800) = 5820 kJ/h

Total Duty

3 806 673 + 134 227 + 722 900 + 650 + 5820

= 4 670 270 kJ/h

Step 4 1st Reheater

One of the principal purposes of reheating is to maintain the process gas above the sulfur dewpoint throughout the catalyst bed. To estimate the dewpoint temperature at the bed outlet, assume that 20% of the H_2S in the feed will be converted to sulfur in the first catalyst bed. Total sulfur (as S_1) at the bed outlet will then be

0.0644 (6) + 0.3787 (8) + 0.2 (132.06) = 29.83 kmols/h vapor as S_1 assuming a pressure drop for the reheater and catalyst bed of 6.89 kPa,

Sulfur vapor pressure (as S_1) then is:

$$\frac{29.84}{512.4}\ (121.3) = 7.06 \text{ kPa (abs)}$$

From Fig. 22-22, the vapor pressure of sulfur at 229.4 °C is about 7.1 kPa. The preheater outlet temperature is therefore set 16.7 °C higher or 246 °C.

			H @ 246 °C	H @ 177 °C
	kmols/h	kJ/kmol	kJ/h	kJ/h
H_2S	26.69	8 601	229 837	162 150
CO_2	72.19	10 137	731 796	513 035
H_2O	133.09	8 635	1 149 194	821 943
SO_2	13.34	10 847	144 744	101 790
N_2	264.36	7 238	1 913 357	1 371 719
S_6	0.12	29 426	3 531	2 508
S_8	0.34	40 694	13 836	9 815
	510.13		4 185 996	2 982 960

Reheater Heat Duty = 4 185 996 – 2 982 960
= 1 203 036 kJ/h

Note: At 246 °C, the molecular distribution of sulfur vapor species (Fig. 22-21) is 0.255 S_6 and 0.745 S_8.

Step 5 1st Catalytic Converter

In the temperature range of 204–371 °C prevailing in the catalytic reactors, the Claus reaction equilibrium involving formation of S_2, S_6, and S_8 should all be used in equilibrium calculations. However, a good approximation is obtained (usually within 1% total overall conversion) if only the reaction to form S_8 is considered.

Assume y mols of H_2S react.

$$\begin{array}{cccc} 2\,H_2S + & SO_2 \rightarrow & 2\,H_2O + & \tfrac{3}{8}\,S_8 \\ y & \tfrac{1}{2}\,y & y & \tfrac{3}{16}\,y \end{array}$$

ΔH @ 0 °C = –126 360 kJ

	Feed Gas @ 246 °C	Outlet Conditions
	kmols/h	kmols/h
H_2S	26.69	26.69 – y
CO_2	72.19	72.19
H_2O,	133.09	133.09 + y
SO_2	13.34	13.34 – y/2
N_2	264.36	264.36
S_6	0.12	—
S_8	0.34	0.43 + (3⁄16)y
	510.13	510.13 – 0.3125y

at equilibrium

$$K_p = \frac{[H_2O]^2\,[S_8]^{3/8}}{[H_2S]^2\,[SO_2]}\left[\frac{\pi}{\text{total mols}}\right]^{\frac{3}{8}-1}$$

$$= \frac{[133.09 + y]^2\,[0.43 + \tfrac{3}{16}\,y]^{3/8}}{[26.69 - y]^2\,[13.34 - y/2]}\left[\frac{[1.2]}{[510.13 - 0.3125y]}\right]^{-5/8}$$

converging moles converted to balance enthalpy in and out:

y, mols/h (assumed)	K_p (calculated)	Equilibrium Temperature (from Fig. 22-27)
17.47	4 134	305 °C

As an alternative to reading Fig. 22-27 the following approximation can be used:

Equilibrium Temperatuire (°C) = 637.0 – 54.75 • ln (K_p) + 2.069 • ln $(K_p)^2$ – 0.03324 • ln $(K_p)^3$

For the assumed value of y, calculate the total outlet stream the (using the data in Fig. 22-28 or the approximations provided earlier) and the overall converter heat balance. For example, for y = 17.47 kmols/h

	Outlet Stream	H @ 305 °C	
	kmols/h	kJ/kmol	kJ/h
H_2S	9.22	10 847	99 987
CO_2	72.19	12 856	928 100
H_2O	150.56	10 772	1 621 905
SO_2	4.61	13 721	63 237
N_2	264.36	9 013	2 382 676
S_6	0.12	36 915	4 430
S_8	3.71	51 112	189 397
	504.76		5 289 733

Heat Balance

Heat In (from Step 4)		= 4 185 996 kJ/h
Claus Reaction	(17.47/2) (126 360)	= 1 103 732 kJ/h
Total Heat Out		= 5 289 733 kJ/h

NOTE: At 305 °C, the molecular distribution of sulfur species (Fig. 22-21) is 0.35 S_6 and 0.65 S_8 but we were examining only S_8 formation here. The heat in plus heat of reaction equals the heat out, validating the convergence.

FIG. 23-2 (Cont'd)
Physical Constants

Note: Numbers in this table do not have accuracies greater than 1 part in 1000. In some cases extra digits have been added to achieve internal consistency or to permit recalculation of experimental values.

	E.			F.	G.	H.	I.			J.		
	Density of Liquid 101.325 kPa(abs), 15 °C						Ideal Gas 101.235 kPa(abs), 15 °C			Specific Heat 15 °C & 101.325 kPa		
Number	Relative Density (specific gravity) 15 °C / 15 °C	kg/m^3 (wt in vacuum)	$m^3/kmol$	Tempearture coefficient of density, 1/T(K)	Acentric Factor, ω	Summation Factor, kPa^{-1} 15 °C	Relative Density (specific gravity) Air = 1	m^3 gas/kg	Volume Ratio gas to liquid	C_p, Ideal Gas $J \cdot K^{-1} \cdot g^{-1}$	C_p, liquid J.K-1.g-1	Number
1	(0.3)*	(300)*	(0.05)*	–	0.0115	0.00442	0.55398	1.4739	(442)*	2.2062	–	1
2	0.35832	358.00	0.08445	–	0.0994	0.00910	1.0383	0.78635	281.51	1.7094	4.5110	2
3	0.50812	507.67	0.08686	-0.00280	0.1529	0.0133	1.5227	0.53622	272.22	1.6292	2.6131	3
4	0.56357	563.07	0.10322	-0.00216	0.1865	0.0169	2.0071	0.40681	229.06	1.6218	2.3552	4
5	0.58466	584.14	0.09950	-0.00194	0.2003	0.0180	2.0071	0.40681	237.63	1.6577	2.3745	5
6	0.62511	624.54	0.11552	-0.00160	0.2284	0.0219	2.4914	0.32772	204.68	1.6014	2.2458	6
7	0.63162	631.05	0.11433	-0.00154	0.2515	0.0230	2.4914	0.32772	206.81	1.6256	2.2750	7
8	0.59681	596.28	0.12100	-0.00188	0.1966	0.0197	2.4914	0.32772	195.41	1.6351	2.3130	8
9	0.66448	663.89	0.12980	-0.00134	0.2993	0.0303	2.9758	0.27438	182.16	1.6178	2.2314	9
10	0.65839	657.80	0.13100	-0.00141	0.2777	0.0284	2.9758	0.27438	180.49	1.6047	2.2030	10
11	0.66946	668.86	0.12884	-0.00136	0.2726	0.0274	2.9758	0.27438	183.52	1.5792	2.1699	11
12	0.65416	653.57	0.13185	-0.00139	0.2331	0.0257	2.9758	0.27438	179.33	1.5968	2.1499	12
13	0.66646	665.86	0.12942	-0.00131	0.2481	0.0261	2.9758	0.27438	182.70	1.5657	2.1499	13
14	0.68860	687.98	0.14565	-0.00123	0.3483	0.0364	3.4602	0.23597	162.34	1.6123	2.2083	14
15	0.68369	683.08	0.14669	-0.00126	0.3312	0.0344	3.4602	0.23597	161.19	1.5978	2.1816	15
16	0.69211	691.49	0.14491	-0.00124	0.3231	0.0344	3.4602	0.23597	163.17	1.5865	2.1487	16
17	0.70333	702.70	0.14260	-0.00124	0.3111	0.0343	3.4602	0.23597	165.82	1.6166	2.1501	17
18	0.67870	678.09	0.14777	-0.00126	0.2870	0.0318	3.4602	0.23597	160.01	1.6169	2.1608	18
19	0.67757	676.96	0.14802	-0.00129	0.3035	0.0323	3.4602	0.23597	159.74	1.6518	2.1916	19
20	0.69755	696.92	0.14378	-0.00105	0.2687	0.0323	3.4602	0.23597	164.45	1.6042	2.1006	20
21	0.69474	694.12	0.14436	-0.00123	0.2501	0.0312	3.4602	0.23597	163.79	1.5796	2.0871	21
22	0.70737	706.73	0.16163	-0.00114	0.3977	0.0464	3.9445	0.20700	146.29	1.6073	2.1961	22
23	0.69846	697.83	0.16369	-0.00119	0.3571	0.0398	3.9445	0.20700	144.45	1.5736	2.1338	23
24	0.69668	696.05	0.16411	-0.00118	0.3043	0.0367	3.9445	0.20700	144.08	1.5948	2.1634	24
25	0.72224	721.59	0.17774	-0.00108	0.4421	0.0516	4.4289	0.18436	133.03	1.6036	2.1842	25
26	0.73442	733.76	0.19391	-0.00104	0.4875	0.0580	4.9133	0.16618	121.94	1.6009	2.1784	26
27	0.75033	749.66	0.09355	-0.00132	0.1950	0.0225	2.4218	0.33714	252.74	1.1363	1.7617	27
28	0.75399	753.31	0.11172	-0.00124	0.2267	0.0272	2.9062	0.28095	211.64	1.2595	1.8425	28
29	0.78395	783.24	0.10745	-0.00119	0.2105	0.0279	2.9062	0.28095	220.05	1.2150	1.8110	29
30	0.77435	773.66	0.12691	-0.00112	0.2352	0.0331	3.3906	0.24082	186.31	1.3366	1.8413	30
31	–	–	–	–	0.0865	0.0079	0.96873	0.84286	–	1.5013	–	31
32	0.52348	523.01	0.08046	-0.00302	0.1407	0.0124	1.4531	0.56191	293.88	1.4952	2.3961	32
33	0.60108	600.54	0.09343	-0.00200	0.1923	0.0169	1.9375	0.42143	253.09	1.4889	2.2458	33
34	0.62813	627.56	0.08940	-0.00184	0.2056	0.0176	1.9375	0.42143	264.47	1.3951	2.2078	34
35	0.61076	610.21	0.09195	-0.00189	0.2035	0.0177	1.9375	0.42143	257.16	1.5316	2.2149	35
36	0.60128	600.74	0.09339	-0.00203	0.1995	0.0169	1.9375	0.42143	253.17	1.5339	2.2923	36
37	0.64654	645.96	0.10857	-0.00165	0.2314	0.0220	2.4218	0.33714	217.78	1.5057	2.1711	37
38	0.65829	657.70	0.08224	-0.00169	0.1715	0.0179	1.8679	0.43714	287.50	1.4398	2.2634	38
39	0.62780	627.24	0.08624	-0.00196	0.1887	0.0167	1.8679	0.43714	274.19	1.4344	2.2395	39
40	0.68657	685.96	0.09930	-0.00149	0.2149	0.0215	2.3522	0.34712	238.11	1.4670	2.1718	40
41	–	–	–	–	0.1976	0.0083	0.89912	0.90812	–	1.6585	–	41
42	0.88510	884.30	0.08833	-0.00120	0.2092	0.0262	2.6974	0.30271	267.68	1.0139	1.7144	42
43	0.87226	871.48	0.10573	-0.00106	0.2637	0.0338	3.1817	0.25662	223.64	1.0871	1.6757	43
44	0.87210	871.31	0.12184	-0.00100	0.3026	0.0415	3.6661	0.22272	194.06	1.1632	1.7202	44
45	0.88492	884.12	0.12008	-0.00094	0.3118	0.0435	3.6661	0.22272	196.91	1.2144	1.7413	45
46	0.86922	868.44	0.12225	-0.00098	0.3255	0.0429	3.6661	0.22272	193.42	1.1485	1.6898	46
47	0.86597	865.19	0.12271	-0.00099	0.3211	0.0427	3.6661	0.22272	192.69	1.1495	1.6825	47
48	0.91131	910.49	0.11439	-0.00100	0.2453	0.0410	3.5965	0.22703	206.71	1.1000	1.7230	48
49	0.86695	866.17	0.13876	-0.00098	0.3256	0.0477	4.1505	0.19673	170.40	1.2828	1.7585	49
50	0.79672	796.00	0.04025	-0.00118	0.5649	0.0309	1.1065	0.73794	587.40	1.3598	2.4749	50
51	0.79443	793.72	0.05804	-0.00107	0.6446	0.0384	1.5908	0.51325	407.38	1.3873	2.3569	51
52	0.79258	791.87	0.03537	–	0.0510	0.00201	0.96725	0.84415	668.46	1.0357	–	52
53	0.81707	816.33	0.05391	-0.01442	0.22394	0.00745	1.5197	0.53727	438.59	0.8316	–	53
54	0.80014	799.42	0.04263	-0.00304	0.1010	0.00926	1.1769	0.69377	554.61	0.9967	2.1698	54
55	1.39376	1392.5	0.04601	-0.00197	0.2570	0.0137	2.2123	0.36908	513.94	0.6166	1.3780	55
56	0.61805	617.49	0.02758	-0.00237	0.2560	0.0109	0.58810	1.3884	857.32	2.0792	4.7087	56
57	0.87594	875.16	0.03309	–	–	0.00201	1.0000	0.81651	714.57	1.0045	–	57
58	0.07086	70.80	0.02847	–	-0.2140	–	0.06961	11.7293	830.38	14.245	–	58
59	1.14220	1141.2	0.02804	–	0.0222	0.00275	1.1050	0.73893	843.25	0.9166	–	59
60	0.80681	806.09	0.03475	–	0.0372	0.00170	0.96736	0.84405	680.38	1.0395	–	60
61	1.42561	1424.33	0.04978	–	0.0722	0.01145	2.4485	0.33347	474.97	0.4757	–	61
62	1.00000	999.10	0.01803	-0.00015	0.3443	0.02496	0.62210	1.3125	1311.3	1.8620	4.1888	62
63	0.12485	124.73	0.03209	–	-0.3820	–	0.13822	5.9074	736.84	5.1931	–	63
64	0.85532	854.56	0.04267	-0.00547	0.1269	0.00770	1.2591	0.64850	554.18	0.7969	–	64

FIG. 23-2 (Cont'd)
Physical Constants

Note: Numbers in this table do not have accuracies greater than 1 part in 1000. In some cases extra digits have been added to achieve internal consistency or to permit recalculation of experimental values.

	K.					L.	M.	Flammability Limits, vol% in air mixture		ASTM octane number		
	Heating Value, 15 °C											
	Net		Gross									
Number	MJ/m³ Ideal gas 101.325 kPa(abs)	MJ/kg Liquid (wt in vacuum)	MJ/m³ Ideal gas 101.325 kPa(abs)	MJ/kg Liquid (wt in vacuum)	MJ/m³ Liquid	Heat of vaporization 101.325 kPa(abs) at boiling point, kJ/kg	Air required for combustion of ideal gas m³(air)/m³(gas)	Lower	Higher	Motor Method D-357	Research Method D-908	Number
1	33.949	-	37.707	-	-	511.3	9.542	5	15	-	-	1
2	60.429	47.162	66.067	51.594	18471	489.2	16.698	2.9	13	+0.05	+1.6*	2
3	86.419	45.957	93.936	49.988	25377	425.5	23.855	2	9.5	97.1	+1.8*	3
4	112.008	45.211	121.404	49.033	27609	365.6	31.011	1.8	8.5	97.6	+0.1*	4
5	112.396	45.343	121.792	49.165	28719	386.9	31.011	1.5	9	89.6	93.8	5
6	138.088	44.899	149.363	48.594	30349	343.7	38.168	1.3	8	90.3	92.3	6
7	138.381	44.974	149.656	48.669	30712	359.2	38.168	1.4	8.3	62.6*	61.7*	7
8	137.485	44.740	148.761	48.435	28881	315.9	38.168	1.3	7.5	80.2	85.5	8
9	164.399	44.734	177.554	48.343	32094	335.1	45.324	1.1	7.7	26	24.8	9
10	164.077	44.664	177.231	48.274	31755	323.0	45.324	1.18	7	73.5	73.4	10
11	164.187	44.691	177.342	48.300	32306	326.0	45.324	1.2	7.7	74.3	74.5	11
12	163.649	44.572	176.803	48.181	31490	305.4	45.324	1.2	7	93.4	91.8	12
13	163.983	44.647	177.138	48.257	32132	316.4	45.324	1.2	7	94.3	0.3	13
14	190.388	44.557	205.422	48.104	33095	318.1	52.481	1	7	-	-	14
15	190.095	44.504	205.128	48.051	32823	307.5	52.481	1	7	46.4	42.4	15
16	190.239	44.535	205.272	48.083	33249	309.0	52.481	(1.01)	6.6	55.8	52	16
17	190.322	44.554	205.356	48.101	33801	310.5	52.481	(1.00)	6.5	69.3	65	17
18	189.625	44.417	204.659	47.964	32524	292.1	52.481	(1.09)	6.8	95.6	92.8	18
19	189.799	44.453	204.833	48.001	32495	295.3	52.481	(1.08)	6.8	83.8	83.1	19
20	189.880	44.472	204.914	48.019	33466	296.3	52.481	(1.04)	7	86.6	80.8	20
21	189.685	44.435	204.719	47.983	33306	289.5	52.481	(1.08)	6.8	+0.1	+1.8	21
22	216.372	44.419	233.285	47.920	33866	302.4	59.637	0.8	6.5	-	-	22
23	215.792	44.331	232.705	47.832	33379	283.8	59.637	(0.92)	6.3	55.7	55.2	23
24	215.727	44.341	232.640	47.842	33301	269.4	59.637	0.95	6	100	100	24
25	242.398	44.320	261.190	47.785	34481	290.1	66.794	0.7	5.6	-	-	25
26	268.393	44.236	289.064	47.671	34979	278.2	73.950	0.7	5.4	-	-	26
27	131.108	43.787	140.504	46.955	35200	390.6	35.782	(1.48)	8.3	84.9*	+0.1	27
28	156.753	43.657	168.029	46.824	35273	348.8	42.939	1.0	8.35	80	91.3	28
29	156.032	43.438	167.307	46.606	36504	355.8	42.939	1.2	8.35	77.2	83	29
30	181.566	43.359	194.720	46.526	35996	318.9	50.095	1.1	6.7	71.1	74.8	30
31	55.964	-	59.723	-	-	484.2	14.313	2.7	36	75.6	+0.03	31
32	81.460	45.384	87.098	48.552	25393	440.0	21.469	2.0	11.7	84.9	+0.2	32
33	107.463	44.910	114.980	48.078	28873	392.4	28.626	1.6	10	80.8	97.4	33
34	107.178	44.759	114.694	47.926	30077	416.2	28.626	1.6	10	83.5	100	34
35	107.022	44.703	114.539	47.871	29212	406.6	28.626	1.6	10	-	-	35
36	106.764	44.610	114.281	47.778	28702	387.1	28.626	1.6	10	-	-	36
37	133.457	44.621	142.853	47.789	30870	360.2	35.782	1.3	10	77.1	90.9	37
38	104.117	45.075	109.755	47.539	31266	450.2	26.240	(1.62)	10.3	-	-	38
39	101.914	44.146	107.551	46.611	29236	415.0	26.240	2.0	12.5	-	-	39
40	127.328	43.804	134.845	46.413	31837	380.6	33.397	(1.12)	8.5	81	99.1	40
41	53.157	-	55.036	-	-	821.7	11.927	1.5	100	-	-	41
42	134.053	40.138	139.690	41.844	37003	394.2	35.782	1.2	8	+2.8	-	42
43	159.540	40.523	167.057	42.452	36996	361.7	42.939	1.2	7.1	+0.3	+5.8	43
44	185.550	40.922	194.946	43.015	37480	336.6	50.095	1.0	8	97.9	+0.8	44
45	185.091	40.809	194.487	42.902	37930	345.3	50.095	1.0	7.6	100	+0	45
46	185.018	40.800	194.414	42.893	37250	340.7	50.095	1.0	7	+2.8	+4	46
47	185.052	40.810	194.448	42.902	37119	338.6	50.095	1.0	7	+1.2	+3.4	47
48	180.328	40.506	187.845	42.213	38434	357.1	47.710	1.1	8	+0.2	>+*3	48
49	211.325	41.192	222.600	43.411	37601	309.1	57.252	0.8	6.5	99.3	+2.1	49
50	28.605	19.912	32.363	22.686	18058	1121.9	7.156	5.5	44	-	-	50
51	54.038	26.802	59.676	29.695	23570	846.6	14.313	3.28	19	-	-	51
52	11.965	-	11.965	-	-	215.1	2.385	12.5	74.2	-	-	52
53	0.0	-	0.0	-	-	573.3	-	-	-	-	-	53
54	21.905	14.738	23.784	15.884	12698	545.3	7.156	4.3	45.5	-	-	54
55	0.0	-	0.0	-	-	388.9	-	-	-	-	-	55
56	13.391	-	16.210	-	-	1369.5	3.578	15.5	27	-	-	56
57	0.0	-	0.0	-	-	201.9	-	-	-	-	-	57
58	10.223	-	12.102	-	-	445.5	2.385	4	74.2	-	-	58
59	0.0	-	0.0	-	-	213.1	-	-	-	-	-	59
60	0.0	-	0.0	-	-	199.2	-	-	-	-	-	60
61	-	-	-	-	-	287.6	-	-	-	-	-	61
62	-	*	*	0.0	0	2256.5	-	-	-	-	-	62
63	-	-	0.0	-	-	20.8	-	-	-	-	-	63
64	-	-	-	-	-	447.2	-	-	-	-	-	64

Example 23-1 — Pure component properties

Using Fig. 24-20, the P-H diagram for propane, calculate the density of propane vapor at 110 °C and 2000 kPa (abs).

Solution

On the P-H diagram at the intersection of the T = 110 °C, P = 2000 kPa (abs) lines read v = 0.03 m^3/kg. Then:

$\rho = 1/0.03 = 33.33$ kg/m^3

Using the EZ*THERMO[90] version of the SRK[91] equation of state, ρ is calculated to be 32.83 kg/m^3, from which v = (1/32.83) = 0.03 m^3/kg.

For propane at 110 °C and 2000 kPa (abs) using data from Fig. 24-27:

$$Z = \frac{MW \cdot P}{R \cdot T \cdot \rho} = \frac{(44.10)\,(2000)}{(8.3145)\,(273 + 110)\,(33.33)} = 0.831$$

The SRK calculation gives ρ = 32.93 kg/m^3, and Z = 0.842.

Gas Mixtures

GPA Standard 2172, "Calculation of Gross Heating Value, Relative Density and Compressibility Factor for Natural Gas Mixtures from Compositional Analysis" contains additional information regarding the calculation of Z-factors for mixtures at pressures below 1000 kPa (abs).

Minor amounts of non-hydrocarbons — Fig 23-4[1] shows Z-factors for typical sweet natural gases. Using Z-factors from Fig. 23-4 should yield mixture volumes (densities) within 2% to 3% of the true values for reduced temperatures from slightly greater than 1.0 to the limits of the chart for both temperature and pressure. The chart has been prepared from data for binary mixtures of methane with ethane, propane and butane and data for natural gas mixtures. All mixtures have average molecular masses less than 40, and all gases contain less than 10% nitrogen and less than 2% combined hydrogen sulfide and carbon dioxide. Fig. 23-4 applies for temperatures –7 °C or more above saturation up to pressures of 70 000 kPa (abs).

Appreciable amount of non-hydrocarbons — Fig. 23-4 does not apply for gases or vapors with more than 2% H_2S and/or CO_2 or more than 20% nitrogen. Use other methods for vapors that have compositions atypical of natural gases mixtures or for mixtures containing significant amounts of water and/or acid gases, and for all mixtures as saturated fluids, other methods should be employed.

Fig. 23-4 provides reasonably accurate gas Z-factors for natural gases with high nitrogen content, up to 50% (or even higher) when using the molar average pseudo-criticals from Equations 23-3a and 23-4a. The same approach applies to gas condensate fluids containing appreciable amounts of heptanes and heavier components. Critical temperatures and pressures for heptane and heavier fractions can be estimated from molecular weight and relative density, or average boiling point and relative density, using correlations presented in this section.

Figs. 23-5, 23-6 and 23-7 provide Z-factors for low molecular mass natural gases. These figures cover a wide range of molecular masses (15.95 to 26.10), temperatures –70 to 500 °C) and pressures [up to 35 000 kPa (abs)]. For gases with molecular weights between those shown in Figs. 23-5 through 23-7, linear interpolation between adjacent charts is sufficient to compute the Z-factors.

In general, Z-factors for gases with less than 5% noncondensable non-hydrocarbons, such as nitrogen, carbon dioxide, and hydrogen sulfide, result with less than 5% error. When the molecular weight is above 20 and the Z-factor is below 0.6, errors as large as 10% may occur.

Effect of acid gas content — Natural gases containing H_2S and/or CO_2 exhibit different Z-factor behavior than do sweet gases. Wichert and Aziz[3] present a calculation procedure to account for these differences. Their method uses the standard gas Z-factor chart (Fig. 23-4) and provides accurate sour gas Z-factors that contain as much as 85% total acid gas. Wichert and Aziz define a "critical temperature adjustment factor," ε, that is a function of the concentrations of CO_2 and H_2S in the sour gas. This correction factor adjusts the pseudo-critical temperature and pressure of the sour gas according to the equations:

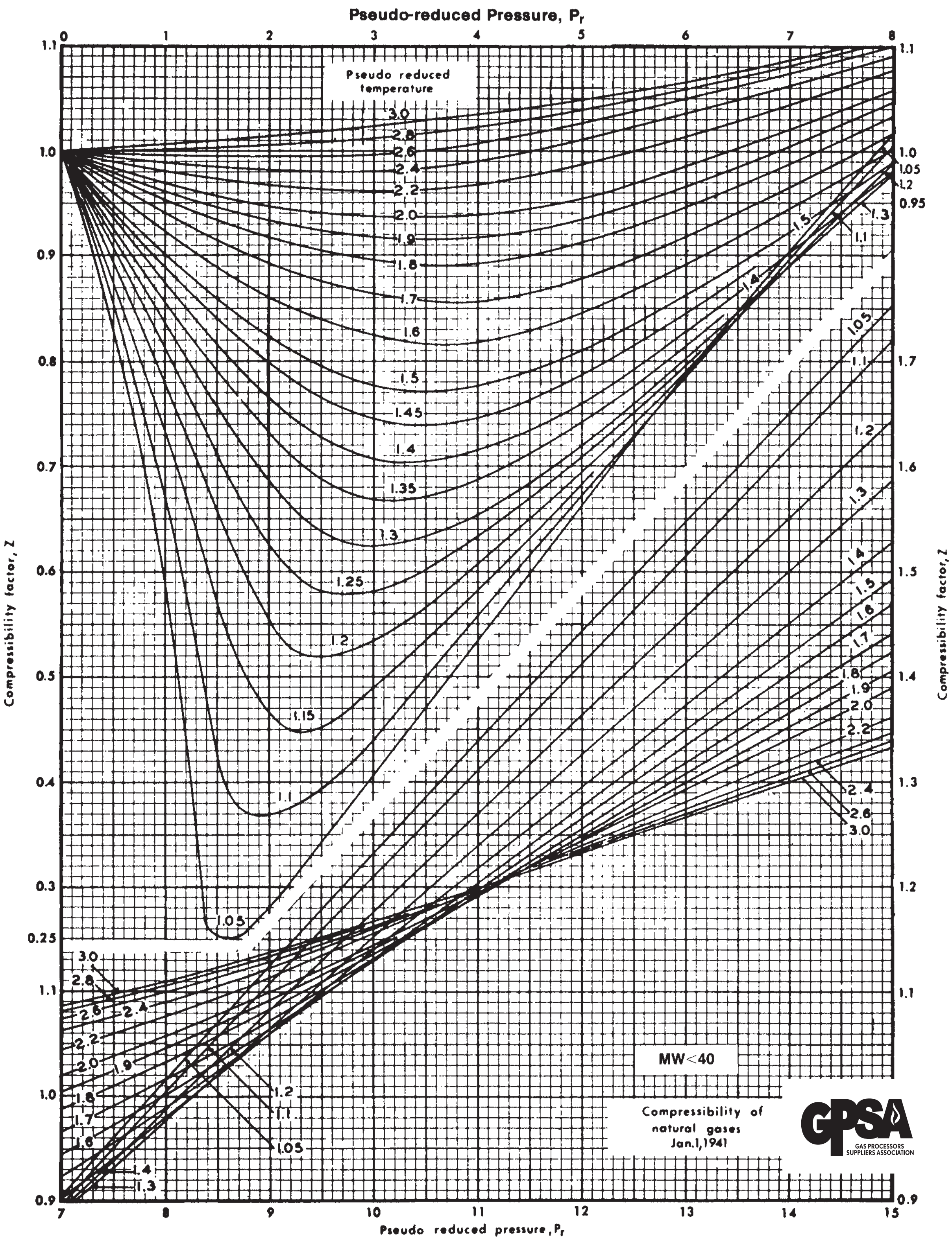
FIG. 23-3

Calculation of Pseudo-critical Temperature and Pressure for a Natural Gas Mixture

Component	Mole Fraction, y_i	Component Critical Temperature, T_{ci}, K	Component Critical Pressure, P_{ci}, kPa	Component Molecular Mass, MW_i	Pseudocritical Temperature $y_i \cdot T_{ci}$, K	Pseudocritical pressure $y_i \cdot p_{ci}$, Kpa	Mixture Molecular Mass $y_i \cdot MW_i$
Methane	0.8319	190.6	4599	16.043	158.560	3825.908	13.346
Ethane	0.0848	305.4	4880	30.070	25.898	413.824	2.550
Propane	0.0437	369.8	4240	44.097	16.160	185.288	1.927
i-Butane	0.0076	407.8	3640	58.123	3.099	27.664	0.442
n-Butane	0.0168	425.1	3784	58.123	7.142	63.571	0.976
i-Pentane	0.0057	460.4	3381	72.150	2.624	19.272	0.411
n-Pentane	0.0032	469.6	3365	72.150	1.503	10.768	0.231
n-Hexane	0.0063	507.5	3012	86.177	3.197	19.976	0.543
	1.0000				218.184 = T_c	4565.271 = P_c	20.426 = MW_W
G = 20.246/28.9625 = 0.705							

FIG. 23-4

Compressibility Factors for Natural Gas[11]



References 99 through 105 contain most of the experimental data used by the authors of reference 45 and by NIST in their EOS development in REFPROP. The data comprises some 1200 points covering CO_2/H_2S mixtures ranging from 6% to 94% CO_2, over a very wide range of pressures and temperatures. NIST were able to match most of these data points to better than 2%, with a small number of deviations over 10% and a few worst matches in the critical region. Current work is expected to be published later in 2011 by Kunz and Wagner.

A current GPA Research Project, Project No. 042, will include density measurements for acid gas mixtures; its scope is described under "Viscosity".

BOILING POINTS, CRITICAL PROPERTIES, ACENTRIC FACTOR, VAPOR PRESSURE

Boiling Points

Fig. 23-18 shows the interconversion between ASTM D-86 distillation 10% to 90% slope and the different boiling points used to characterize fractions of crude oil to determine the properties; VABP, WABP, CABP, MeABP, and MABP. On the basis of ASTM D-86 distillation data, the volumetric average boiling (VABP) point is:

$$VABP = (t_{10} + t_{30} + t_{50} + t_{70} + t_{90})/5 \qquad \textbf{Eq 23-12}$$

where the subscripts 10, 30, 50, 70, and 90 refer to the volume percent recovered during the distillation. The 10% to 90% slope used as the abscissa in Fig. 23-18 is:

$$\text{slope} = (t_{90} - t_{10})/(90 - 10) \qquad \textbf{Eq 23-13}$$

To use the graph, locate the curve for the distillation VABP in the appropriate set for the type of boiling point desired. For the known 10–90% slope, read a correction for the VABP from the selected VABP curve.

Example 23-4 — Determine the mean average boiling point (MeABP) and the molecular weight for a 56.8° API petroleum fraction with the following ASTM distillation data.

% Over	Temperature, °C
IBP	37.8
5	54.4
10	67.2
20	88.3
30	102.8
40	117.8
50	137.8
60	159.4
70	195.6
80	240.0
90	311.1
EP	337.8

IBP = initial boiling point   EP = end point

Slope = (311.1 – 67.2)/80 = 3.05

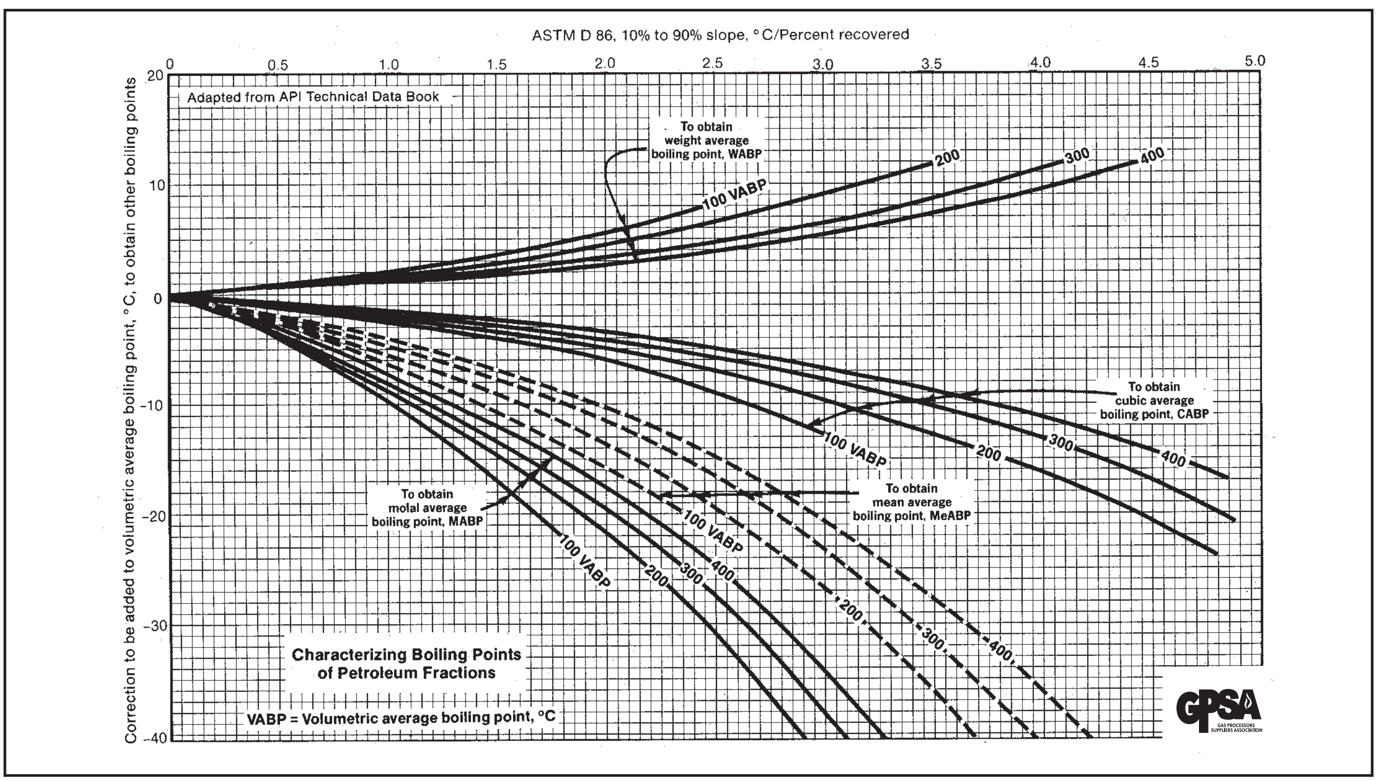
VABP = (67.2 + 102.8 + 137.8 + 195.6 + 311.1)/5 = 162.9 °C

Refer to Fig. 23-18. Read down from a slope of 3.05 to the interpolated curve to 162.9 °C in the set drawn with dashed lines (MeABP). Read a correction value of –29.5 on the ordinate. Then

MeABP = 162.9 – 29.5 = 133.4 °C

FIG. 23-18

Characterizing Boiling Points of Petroleum Fractions



The significance of the various average boiling points, interconversion of D-86 and D-1160 ASTM distillations, and the calculation of true-boiling point and atmospheric flash curves from ASTM distillation data are in Chapters 3 and 4 of the API Technical Data Book.[36]

Molecular mass can be calculated from Equation 23-14 using MeABP in K and S (relative density at 15 °C):

$$MW = 204.38\left[(1.8 \cdot T)^{0.118}\right](S^{1.88})\left(e^{(0.00392T - 3.075\,S)}\right) \quad \textbf{Eq 23-14}$$

This relationship has been evaluated in the molecular mass range of 70 to 720; the MeABP of 36 to 560 °C; and the API range of 14° to 93°. Its average error was about 7%. Equation 23-14 is best used for molecular masses above 115, since it tends to over-predict below this value.

Example 23-5 — Calculation of molecular mass.

From Example 23-4:

$S = 0.7515$ for 56.8° API

$MeABP = 133.4 + 273 = 406.4$ K

Using Equation 23-14,

$$MW = 204.38\left[(1.8 \cdot 406.4)^{0.118}\right]\left[(0.7515)^{1.88}\right]\left[e^{(0.00392 \cdot 406.4) - (3.075 \cdot 0.7515)}\right] = 127.0$$

Critical Properties

Critical properties are of interest because they are used to find reduced conditions of temperature and pressure as required for corresponding states correlations. Pseudo-critical properties are used in many corresponding states correlations for mixtures.

The following equations taken from the API Technical Data Book[36a, b] can be used to estimate pseudo critical temperature and pressure for petroleum fractions (pseudo, or undefined components):

$$P_{pc} = \left[5.5303\left(19^{9}\right)T^{-2.3125}\right] \cdot S^{2.3201} \quad \textbf{Eq 23-15}$$

$$T_{pc} = 19.0623 \cdot T^{0.58848} \cdot S0.^{3596} \quad \textbf{Eq 23-16}$$

These equations are in terms of T = MeABP (K) and relative density (S) at 15 °C. Both of these correlations have been evaluated over the range of 80 to 690 molecular mass; 20 to 150 °C normal boiling point; and 6.6° to 95° API.

Example 23-6 — Pseudocritical temperature and pressure.

Take the previous mixture (from Example 23-4) with:

VABP = 166.4 °C

MeABP = 118.4 °C

API = 56.8°

Molecular Weight = 127 (Ex. 23-5)

ASTM D-86, 10% to 90% Slope = 3.05

Find its pseudocritical temperature.

Solution Steps

From Fig. 23-18 with ASTM D-86 slope = 3.05 find a VABP correction of about – 65 °C (extrapolated from the left-hand group).

MABP = 166.4 – 65 = 101.4 °C

Use Equation 23-16 to calculate the pseudocritical temperature as:

$$T_{pc} = 19.0623\,(118.4 + 273)^{0.58848}\,(0.7515)^{0.3596} = 577.1 \text{ K} = 304.1 \text{ °C}$$

For this 56.8° API fluid, estimate the pseudocritical pressure, using Eq. 23-15 and MeABP = 118.4 °C:

$$P_{pc} = \left[5.5303\,(10^{9})\right](118.4 + 273)^{-2.3125}\,(0.7515)^{2.3021} = 2865 \text{ kPa (abs)}$$

Acentric Factor

The acentric factor, ω, is often a third parameter in corresponding states correlations. Fig. 23-2 tabulates it for pure hydrocarbons. The acentric factor is a function of P_{vp}, P_c, and T_c. It is arbitrarily defined as

$$\omega = -\log(P_{vp}/P_c)_{Tr = 0.7} - 1.0 \quad \textbf{Eq 23-17}$$

This definition requires knowledge of the critical (pseudo-critical) temperature, vapor pressure, and critical (pseudo-critical) pressure.

For a hydrocarbon mixture of known composition that contains similar components, a reasonably good estimate for the acentric factor is the molar average of the individual pure component acentric factors:

$$\omega = \sum y_i \omega_i \quad \textbf{Eq 23-18}$$

If the vapor pressure is not known, ω can be estimated[38] for pure hydrocarbons or for fractions with boiling point ranges of 10 °C or less using:

$$\omega = \frac{3}{7}\left[\frac{\log P_c - \log 14.7}{(T_c/T_b) - 1}\right] - 1.0 \quad \textbf{Eq 23-19}$$

Example 23-7 — Acentric factor.

A narrow-boiling petroleum fraction has a VABP of 214.4 °C, an ASTM slope of 0.75 and an API gravity of 41°. Estimate its acentric factor. In order to use Eq 23-19 we need the average boiling point (MeABP); the pseudocritical temperature (a function of MABP); and the pseudocritical pressure (a function of MeABP).

From Fig. 23-18, the correction to VABP for mean average is –1.7 °C; and the correction for MABP is –2.8 °C. Note that for narrow-boiling fractions, all boiling points approach the volumetric average. Then, MeABP = 212.7 °C and MABP is 211.6 °C.

From Eq. 23-14, the pseudocritical pressure is:

$T = 212.7 + 273.15 = 485.85$ K

S for 41° API = 141.5/(131.5 + 41) = 0.8203

$$P_{pc} = \left[5.5303\left(10^{9}\right)(485.85)^{-2.3125}\right] \cdot (0.8203)^{2.3201}$$

$P_{pc} = 2141$ kPa (abs)

From Eq. 23-15, the pseudocritical temperature is:

$$T_{pc} = 19.0623 \cdot (485.85)^{0.58848} \cdot (0.8203)^{0.3596}$$

$T_{pc} = 676.4$ K

$$\omega = \frac{3}{7}\left[\frac{\log(2141) - \log(101.325)}{(676.4/485.5) - 1}\right] - 1.0 = 0.444$$

Vapor Pressure

The vapor pressures of light hydrocarbons and some common inorganics in the temperature range below 38 °C appear in Fig. 23-19. Vapor pressures at higher temperatures, up to 315 °C, are in Fig. 23-20 for the same compounds. Note that, except for ethylene and propylene, the hydrocarbons are all normal paraffins.

SECTION 26

Members

Gas Processors Suppliers Association

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Tulsa, Oklahoma 74145
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The following is a listing of the members of GPSA. Please contact them directly for further information. Behind this listing of members, the GPSA companies are classified by the type of services and supplies that they provide to the industry. Services begin on page 26-15; Supplies begin on page 26-26.

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Accurate Gas L.L.C. 116 Board Road Lafayette, LA 70508 http://www. accurategasllc.com	337-269-1217	337-269-1978
Accurate Lab Audits, LLC P.O. Box 248 Ville Platte, LA 70506	337-280-1003	
Adsorption Technical Service, LLC 15138 Windsdowne Lane Cypress, TX 77429	281-256-0868	281-256-1996
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AMCS Corporation 135 US Highway 202-206 Bedminister, NJ 07921 http://www.amcscorp.com	908-719-6560	
AMEC Oil & Gas Americas 10777 Clay Rd. Houston, TX 77041 http://www.amec.com	713-570-8510	
American Cleaning Systems, Inc. 5261 W. 42nd St. Odessa, TX 79764 http://www.amcleaning.net	432-381-3740	
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Applied Consultants, Inc. 1221 Abrams Rd., Ste. 225 Richardson, TX 75081 http://www.appliedconsultants.com	972-235-1958	972-235-9010
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BEI Engineers 3741 Red Bluff Road, Ste. 200 Pasadena, TX 77503 http://www.bei-us.com	713-475-2424	
BENTEK Energy LLC 32045 Castle Court Evergreen, CO 80439 http://www.bentekenergy.com	303-988-1320	303-988-6409
Best PumpWorks 8885 Monroe Houston, TX 77061 http://www.bestpumpworks.com	713-956-2002	713-956-2141
Bexar Energy Holdings Inc. 111 Soledade, Ste. 830 San Antonio, TX 78205 http://www.bexarenergy.com	210-342-7106	210-223-0018
BFX Fabrication LLC 13465 Midway Road, Ste. 300 Dallas, TX 75244	469-374-5368	
Black & Veatch Corp. Energy Division - Oil & Gas Houston, TX 77056 http://www.bv.com	713-416-9641	
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Chapman Corporation 331 South Main Street Washington, PA 15301	724-250-2245	
Chart Energy & Chemicals, Inc. 8665 New Trails Dr., #100 The Woodlands, TX 77381 http://www.chart-ec.com	612-227-4949	
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Chromatic Industries 15B S. Trade Center Pkwy. Conroe, TX 77385 http://www.hemiwedge.com	936-539-5770	
Cimation 10205 Westheimer Rd., Ste. 100 Houston, TX 77042 http://www.cimation.com	713-452-3350	
City Pipe & Supply Corp. 2108 W. 2nd Odessa, TX 79763 http://www.citypipe.com	800-688-7473	432-333-2300
Clary E&I Services, LLC 110 W. Henderson Overton, TX 75684 http://www.claryei.com	903-834-0115	903-834-0116
Clear Creek Construction 945 E. Britton Rd Oklahoma City, OK 73114 http://www.clearcreekusa.com	405-478-3430	
Coastal Chemical Co. LLC 5300 Memorial Drive, Suite 250 Houston, TX 77007 http://www.coastalchem.com	713-865-8787	713-865-8788
Coastal Flow Measurement, Inc. 2222 Bay Area Blvd., Suite 200 Houston, TX 77058 http://www.coastalflow.com	281-282-0622	281-282-0791

Company& Address	Phone	Fax
Compressor Engineering Corp. (CECO) 5440 Alder Houston, TX 77081	713-664-7333	
Compressor Systems, Inc. P.O. Box 60760 Midland, TX 79711	432-495-3228	
CompressorTech Two 12777 Jones Road, Ste. 225 Houston, TX 77070 http://www.compressortech2.com	832-205-3047	
Condit Co. 7255 E 46th ST Tulsa, Ok 74145 http://www.conditcompany.com	918-663-5310	918-610-3451
Conestoga-Rovers & Associates 2270 Springlake Road, Suite 800 Dallas, TX 75234 http://www.craworld.com	972-331-8500	972-331-8501
Connelly-GPM, Inc. 3154 So. California Ave. Chicago, IL 60608	312-247-7237	
Consulting and Field Services 1600 North Waverly Street Ponca City, OK 74601 http://www.cfsinspection.com	580-762-4510	580-762-1635
Contek Solutions LLC 6221 Chapel Hill Blvd., Ste. 300 Plano, TX 75093 http://www.contekllc.com	469-467-8296	
Cook Compression 2203 Timberlock, Ste. 229 The Woodlands, TX 77380	281-636-8431	
Corpac Steel Products Corp. 20803 Biscayne Blvd., Suite 502 Miami, FL 33021 http://www.corpacsteel.com	305-918-0540	305-931-2251
Corrosion Resistant Alloys 1310 W. Sam Houston Parkway North Houston, TX 77043	281-734-6280	
Credence Gas Services LLC P.O. Box 2388 Alvin, TX 77512 http://www.credencegasservices.com	281-331-2219	281-331-2235
Criterion Catalyst and Technologies LP 16825 Northchase Drive, Ste. 1000 Houston, TX 77060	281-875-7899	
Croft Automation LLC 712 Austin Ave Waco, TX 76701 http://www.croftautomation.com	903-388-6472	254-714-1710
Croft Production Systems, Inc. 19230 FM 442 Needville, TX 77461 http://www.croftsystems.net	979-793-2100	
Cummings Electrical, Inc. 14900 Grand River Road, Ste. 124 Fort Worth, TX 76155 http://www.cummingselec.com	817-355-5300	

Company& Address	Phone	Fax
Cummins Inc. 19739 Lake Stone Court Tomball, TX 77377 http://www.cumminsoilandgas.com	713-416-6235	
Custom Compression Systems 1110 Unifab Road, Suite A New Iberia, LA 70560 http://www.customcompressionsystems.com	337-560-7700	
D.F.Bergman, Inc. 17714 Mossy Ridge Lane Houston, TX 77095	281-859-9633	
Daniel Measurement and Control 9720 Old Katy Rd. Houston, TX 77055	713-827-3874	713-827-3886
DBR Technology Center, Div. Schlumberger 9450 - 17 Avenue Edmonton, Al T6N 1M9 http://www.slb.com	780-463-8638	780-450-1668
DCG Partnership 1, Ltd. 4170A S. Main Pearland, TX 77581		
Detechtion Technologies 24 Greenway Plaza, #802 Houston, TX 77046 http://www.detechtion.com	800-780-9798	713-559-3059
Detector Electronics Corp. 6901 W 110th Street Minneapolis, MN 55438 http://www.Detronics.com	952 941 5665	
Dew Point Control LLC P.O. Box 18887 Sugar Land, TX 77479-8887 http://www.dewpointcontrol.com	281-265-0101	281-265-0107
Dexter Field Services 2826 Morning Star New Braunfels, TX 78132	512-432-4754	
Diablo Analytical Inc. 5141 Lone Tree Way Antioch, CA 94531 http://www.diabloanalytical.com	925-755-1005	925-755-1007
Dickson Process Systems Ltd. P.O. BOX 60478 Midland, TX 79711 http://www.dicksonprocess.com	432-561-8594	432-561-8990
Dresser-Rand Company 4121 Cross Bend Drive Arlington, TX 76016	214-597-7663	
Eaton Metal Products Company 4800 York Street Denver, CO 80216	303-296-5729	
EDG Inc. 10777 Westheimer Rd., #700 Houston, TX 77042	713-977-2347	713-977-2387
Edge Engineering & Science 16360 Park Ten Place, Ste. 300 Houston, TX 77084 http://www.edge-es.com	832-772-3003	
Elkhorn Holdings Inc 71 Allegiance Cir Evanston, WY 82930 http://www.elkhornconstruction.com	307-789-1595	307-789-7145

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Elliott Group 10940 West Sam Houston Parkway N. Houston, TX 77064 http://www.elliott-turbo.com	281-517-7130	281-955-5072
EMD, Inc. 1411 Twin Oaks Wichita Falls, TX 76302 http://www.emdinc.com	940-322-2206	940-322-1719
Empact Analytical Systems Inc. 362 So. Main Brighton, CO 80601	303-637-0150	
EnDyn Ltd. 301 West First St. Alice, TX 78332	800-723-6396	361-668-3906
Enerflex 10815 Telge Road Houston, TX 77095	281-345-5022	
Energy Management & Services Co. 9990 Richmond Ave., Ste. 202 South Houston, TX 77042	713-456-7880	713-456-7881
Energy Recovery Inc. 1717 Doolittle Drive San Leandro, CA 94577 http://www.energyrecovery.com	281 633 6662	
Energy Training Solutions 1310 Kingwood Drive Kingwood, TX 77339 http://www.energytrainingsolutions.com	281-783-5265	281-360-3874
EnerSys Corporation 12875 Capricorn Street Stafford, TX 77477 http://www.EnerSysCorp.com	281-598-7100	281-598-7199
Enerven Compression Services, LLC 8150 N. Central Expressway, Ste. 1100 Dallas, TX 75206 http://www.enerven.com	214-365-3200	214-265-0455
ENGlobal Corporation 12303 Airport Way, Ste. 145 Broomfield, CO 80021 http://www.ENGlobal.com	303-439-4325	
EnRUD Resources, Inc. 1006 Vista Road Pasadena, TX 77504 http://www.enrud.com	713-943-1600	
Enserca Engineering 165 S. Union Blvd., Ste. 1000 Lakewood, CO 80228	303-468-2720	
Entero Corporation 1040 - 7 Ave SW Suite 500 Calgary, AB T2P 3G9 http://www.entero.com	403-261-1820	403-261-2816
EPC Inc. 14128 State Highway 110 South Whitehouse, TX 75791 http://www.epc0392.com	903-939-1555	903-939-1566
EPCON International Inc. 1250 Wood Branch Park Drive, Ste. 600 Houston, TX 77079	281-398-9400	281-398-9488
ESD Simulation Training, Inc. One Riverway, Ste. 1700 Houston, TX 77056 http://www.esd-simulation.com	713-300-3757	

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eSimulation Inc. 1322 Space Park Drive, Suite A190 Houston, TX 77058 http://www.esimulation.com	713-962-3107	281-893-3319
Evonik Corporation 10200 Grogans Mill Road, Ste. 500 The Woodlands, TX 77380 http://www.evonik.com/northamerica	281-298-0290	
Exeltech 7317 Jack Newell Blvd. N. Fort Worth, TX 76118	817-595-4969	817-595-1290
EXTERRAN 20602 E. 81st St. Broken Arrow, OK 74014 http://www.exterran.com	918-251-8571	918-259-2856
F.W. Murphy P.O. Box 470248 Tulsa, OK 74147 http://www.fwmurphy.com	918-317-4100	918-317-4266
Fabreeka International 13207 Tall Forest Cypress, TX 77429 http://www.fabreeka.com	2818945997	2818970064
Fabwell Corporation 8410 S. Regency Drive Tulsa, OK 74131-3621 http://www.fabwell.com	918-224-9060	
Factory Direct Safety & Environmental 4153 Bluebonnet Drive Stafford, TX 77477 http://www.factorydirectsafety.com	832-532-9992	
Fagen Inc. 1312 Catiline Place Baton Rouge, LA 70816	651-728-2312	
FairFax Operations, LLC 123B N 14th Collinsville, OK 74021 http://www.fairfaxops.com	918-371-5139	918-371-5931
Fairwinds International 128 Northpark Blvd. Covington, LA 70433	985-809-3808	
Federal Services LLC 120 E. Main Street Oklahoma City, OK 73104 http://www.federalcorp.com	405-239-7301	405-232-5438
FESCO, Ltd. 1100 FESCO Avenue Alice, TX 78332 http://www.fescoinc.com	361-661-7015	361-661-7019
FES-Southwest, Inc. 19221 IH-45 South Ste. 340 Conroe, TX 77385 http://www.fessw.com	281-296-7920	281-296-7177
Fisher Controls 205 S Center Street Marshalltown, IA 50158 http://www.fisher.com	641-754-3011	641-754-3026
Fluenta Inc. 1155 Dairy Ashford, Suite 211 Houston, Tx 77079 http://www.fluenta.com	281-972-2004	281-497-8687

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Fluor Enterprises, Inc. 3 Polaris Way Aliso Viejo, CA 92698	949-349-2231	
FMC Technologies Direct Drive Systems 621 Burning Tree Road Fullerton, CA 92833	720-560-6177	
Foster Wheeler USA Corporation 2020 Dairy Ashford Houston, TX 77077	281-597-3000	281-597-3028
Freese and Nichols, Inc. 4055 International Plaza, Ste. 200 Fort Worth, TX 76109 http://www.freese.com	817-735-7300	
Future Pipe Industries 11811 Proctor Street Houston, TX 77038 http://www.futurepipe.com	281-847-2987	
G2 Partners, LLC 10260 Westheimer Rd., St. 400 Houston, TX 77042 http://www.g2partnersllc.com	713-260-4000	713-260-4099
Garzo, Inc. 4430 Steffani Lane Houston, TX 77041	713-466-8679	713-466-8686
Gas Analytical Solutions, Inc. 19330 Highway 155 South Flint, TX 75762	903-825-2136	903-825-2184
Gas and Supply 111 Buras Drive Belle Chasse, LA 70037 http://www.gasandsupply.com	504-234-7700	
Gas Corporation of America P.O. Box 5183 Wichita Falls, TX 76307 http://www.gas-corp.com	940-723-6015	
Gas Equipment Company, Inc. 11616 Harry Hines Blvd Dallas, TX 75229 http://www.gasequipment.com	972-280-8430	972-620-4142
Gas Packaging Engineering Co. 3000, 150-6th Avenue S.W. Calgary, AB T2P 3Y7 http://www.gaspackages.com	403-538-2164	
Gas Technology Corporation 1425 Greenway Drive, Suite 450 Irving, TX 75038 http://www.gastech.net	972-255-7800	972-550-0071
Gas Treatment Services B.V. Timmerbabriekstraat 12, Bergambacht GV, 2861 http://www.gtsbv.com	31 182 621890	31 182 621891
GE Oil & Gas, Inc. 4424 West Sam Houston Parkway North, Ste. 700 Houston, TX 77041		
GE Power & Water 1101 W. Saint Paul Ave. Waukesha, WI 53188 http://www.dresserwaukesha.com	262-547-3311	262-650-5650

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GEA Refrigeration North America Inc. 3475 Board Road York, PA 17406 http://www.geafes.com	717-309-3333	
Genesis Systems 1501 10th Street #100 Plano, TX 75074 http://www.callgenesis.com	972-877-5016	
Geolex, Inc. 500 Marquette Ave. NW #1350 Albuquerque, NM 87102 http://www.geolex.com	505-842-8000	
G-Force and Associates, Inc. 5200 W. Highway 377 Tolar, TX 76476 http://www.gforcetx.com	817-573-3960	
Global Compressor, LP 13415 Emmett Road Houston, TX 77084 http://www.globalcompressorparts.com	713-983-8773	713-983-7118
Global Process Systems SDN BHD Level 8 Menara See Hoy Chan, No. 373 Jalan Tun Razak Kuala Lumpur, WP 50400 http://www.globalprocesssystems.com	603 914 53000	603 216 13234
Gly-Tech Services 2054 Paxton St. Harvey, LA 70058 http://www.glytech.com	504-348-8566	504-348-8261
Goar Sulfur Services & Assistance 1522 Hubbard Dr. Tyler, TX 75703		903-561-3008
GRACE Davison 845 Redwing Street Bridge City, TX 77611		
Graves Analytical Services LLC P.O. Box 253 Hugoton, KS 67951	620-428-6053	620-428-6069
Gregory Gas Services, LLC 343592 E. 990 Rd. Chandler, OK 74834 http://www.gregorygasservices.com	918-866-2318	918-866-2263
Groundwater & Environmental Services, Inc. 440 Creamery Way, Ste. 500 Exton, PA 19341 http://www.gesonline.com	800-426=9871 x3022	
GTS Energy 4050 36th Ave. NE Norman, OK 73026 http://www.gtsenergy.com	979-820-0556	
Guild Associates, Inc. 5750 Shier-Rings Road Dublin, OH 43016 http://www.moleculargate.com	908-752-6420	614-798-1972
Gulf Coast Chemical, LLC 220 Jacqulyn Street Abbeville, LA 70510 http://www.gulfcoastchemical.com	337-898-0213	337-893-9927
Gulf Coast Dismantling, Inc. P.O. Box 5249 Pasadena, TX 77508	281-487-0595	281-487-0597

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Gulf Coast Measurement, Inc. P.O. Box 854 Cypress, TX 77410	281-357-0992	281-357-0994
Gulf Interstate Engineering 16010 Barkers Point Lane, Ste. 600 Houston, TX 77079	713-850-3585	
Gulf Publishing Company 2 Greenway Plaza, Ste. 1020 Houston, TX 77046 http://www.hydrocarbonprocessing.com	713-523-4443	
Gulsby Engineering Inc. 1250 Indiana St Humble, TX 77396	281-446-4230	281-446-5445
GWD 621 17th Street, Ste. 1200 Denver, CO 80293 http://www.gwddesign.com	303-951-9327	
H&S Valve Inc. 6704 No. County Rd. West Odessa, TX 79702	432-362-0486	432-368-5052
H.J. Baker, PE 1511 Rock Ridge Dr. Cleveland, OK 74020	918-358-5286	425-928-2637
Halker Consulting, LLC 9400 Station Street, Ste. 300 Lone Tree, CO 80124 http://www.halkerconsulting.com	303-515-2700	
Hammco Inc. 6901 N 115th E Ave Owasso, OK 74055 http://www.hammco-aircoolers.com	918-272-9575	918-272-9585
Harris Group Inc 1999 Broadway Suite 1500 Denver, CO 80202 http://www.harrisgroup.com	303-291-0355	303-291-0136
Heath Consultants Inc. 9030 Monroe Road Houston, TX 77061 http://www.heathus.com	713-844-1300	713-844-1309
HETSCO, Inc. 505 Pushville Rd. Greenwood, IN 46143 http://www.hetsco.com	317-535-4315	317-535-4684
HJ Baker, PE 1511 Rock Ridge Drive Cleveland, OK 74020	918-358-5286	
Holloman Corp. 333 N. Sam Houston Pkwy, Level 6 Houston, TX 77060	281-260-1060	
Houston Vessel Manufacturing LLC 16250 Tomball Parkway Houston, TX 77086 http://www.houstonvessel.com	713-550-1376	
Howard Measurement Co., Inc. 1637 Enterprise St. Athens, TX 75751 http://www.howardmeasurement.com	903-677-0700	
HPF Consultants, Inc. 601 N. Marienfeld, Suite 200 Midland, TX 79701-4365 http://www.hpfconsultants.com	432-685-4143	432-685-4145
HSB Solomon Associates, LLC One Lincoln Centre, 5400 LBJ Freeway, Ste. 1400 Dallas, TX 75240 http://www.solomononline.com	972-739-1719	972-233-8332
Hunt, Guillot & Associates 603 Reynolds Drive Ruston, LA 71270 http://www.hga-llc.,com	318-255-6825	
Huntsman Corp. 3040 Post Oak Blvd. Houston, TX 77056	713-235-6000	713-235-6977
HyBon Engineering 2404 Commerce Drive Midland, TX 79704	432-697-2292	432-697-2310
Hydrocarbon Technology Engineering 802 Merritt St., SE Grand Rapids, MI 49507	616-452-3279	616-452-3290
I&S Technical Resources, Inc. 248 Twin Lakes Blvd. West Columbia, TX 77486	832-476-5473	
Ignition Systems & Controls, LP P. O. Box 60372 Midland, TX 79711-0372	915-697-6472	
Industrial Distributors, Inc. 4920 Nome St., Unit A Denver,, CO 80239 http://www.idiprocess.com	303-375-9070	303-375-0911
Industrial Engineering Management, Inc. 4444 American Way, #200 Baton Rouge, LA 70816	225-214-4444	
Industrial Gas Technology, Inc. 150 Vanderbilt Ct. Bowling Green, KY 42103 http://www.industrialgastechnology.com	270-783-0538	
INEOS Oxide 2901 Wilcrest Suite 205 Houston, TX 77042 http://www.ineos.com	713-243-6200	713-243-6220
International Oil & Gas Consultants Pte, Ltd. 360 Orchard Road, #12-02 International Bldg. Singapore, 238869 http://www.iog-consultants.com	+65 6235 9030	+65 6235 6180
Intertek 801 Travis, Ste. 1500 Houston, TX 77002 http://www.intertek.com	713-430-8601	
Invensys-Foxboro 8610 S. 66th E. Ave. Tulsa, OK 74133 http://www.iom.invensys.com	918-492-6301	918-492-6302
IPD 23231 Normandie Ave. Torrance, CA 90501 http://www.ipdparts.com	310-602-5317	310-530-2708
ISGAS 5807 Northdale Street Houston, TX 77087	713-645-5886	713-645-0661

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J MAR & Associates 15455 Dallas Parkway Suite 220 Addison, TX 75001 http://www.jmarassociates.com	972-732-8301	
J. H. Foglietta Consulting LLC 5827 Fairdale Lane Houston, TX 77057	713-962-0470	
J.W. Williams Inc.,a Flint Energy Services Co. 19814 G.H. Circle Waller, TX 77084	936-931-2424	936-931-2225
JEM Resources & Engineering, Inc. 10 Desta Drive, Ste. 175 Midland, TX 79705 http://www.jemengineering.com/	432-352-0802	
JFE Engineering Corp. 2-1 Suehiro-cho, Tsurumi-Ku, Yokohama, 230-8611	81 45 505 07772	81 45 505 08941
JGC Corp. 2-3-1 Minato mirai, Nishi-ku Yokohama, Ka 220-6001 http://www.jgc.co.jp	045-682-8468	045-682-8835
John M. Campbell & Company 1215 Crossroads Blvd Norman, OK 73072 http://www.jmcampbell.com	405-321-1383	405-321-4533
Johnson Filtration Products, Inc. P.O. Box 30010 Amarillo, TX 79120	806-371-8033	806-372-5257
Johnson Matthey Catalysts 4106 New West Road Pasadena, TX 77507 http://www.jmcatalysts.com	713-598-4115	281-291-0721
Johnson Screens 16430 Park Ten Place Houston, TX 77084 http://www.johnsonscreens.com	832-590-4177	832-590-2050
Jonell, Inc P.O. Box 1092, 900 Industrial Pkwy Breckenridge, Tx 76424 http://www.jonellinc.com	254-559-7591	254-559-9863
Jord International 11200 Richmond Ave., #301 Houston, TX 77082 http://www.jord.com.au	832-300-7100	832-300-7104
Joule Processing LLC. 3200 Southwest Freeway, Ste. 2390 Houston, TX 77027 http://www.jouleprocessing.com	713-481-1864	713-481-1887
JV Industrial Companies 4040 Red Bluff Pasadena, TX 77503	281-842-9353	
J-W Power Company 7074 S. Revere Parkway Centennial, CO 80112 http://www.jwoperating.com	720-385-3030	866-741-2025
Kahuna Ventures 10355 Westmoor, Ste. 250, Westminster, CO 80021	303-451-7374	
Kams, Inc. 1831 NW 4th Dr. Oklahoma City, OK 73106	405-232-2636	405-232-3107

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Kane Environmental Engineering 5307 Oakdale Creek Court Spring, TX 77379	281-370-6580	281-379-3735
KASKA, LLC 330 South Mill Pryor, OK 74361	918-825-3763	
KBC Advanced Technologies 15021 Katy Freeway, Ste. 600 Houston, TX 77094 http://www.kbcat.com	281-293-8200	
KBR, Inc. 601 Jefferson Street Houston, TX 77007 http://www.kbr.com	713-753-2000	713-753-2000
Kenny Electric 901 SW Frontage Rd. Fort Collins, CO 80254 http://www.kenny-electric.com	970-212-4334	970-490-2878
Kimray Inc. 52 NW 42nd Street Oklahoma City, OK 73118	405-525-6601	405-525-5630
Kleinfelder 7805 Mesquite Bend, Suite 100 Irving, Tx 75063 http://www.kleinfelder.com	972-868-5934	972-409-0008
Knighten Industries Inc. 3323 NC Rd. West Odessa, TX 79764	432-362-0468	432-362-9813
Koch-Glitsch, LP 4111 East 37th Street North Wichita, KS 67220 http://www.koch-glitsch.com	316-828-7208	316-828-7985
Kodiak Gas Processing LLC P.O. Box 418 Wilmette, IL 60091	214-601-6655	
KW International 1223 Brittmoore Rd. Houston, TX 77043 http://www.kwintl.com	713-468-9581`	713-468-2770
L.A. Turbine 29151 Avenue Penn Valencia, CA 91355 http://www.laturbine.com	661-294-8290	661-294-8249
Laboratory Services 2609 W. Marland Hobbs, NM 88240	575-397-3713	
Lauren Engineers & Constructors 22503 Katy Freeway Katy, TX 77450 http://www.laurenec.com	281-994-4232	
LCM Industries, Inc. 1605 S. Marlin Dr. Odessa, TX 79763 http://www.lcmindustries.com	432-332-5516	432-332-5519
L-Con, Inc. Engineers/Constructors 12301 Kurland Dr., Ste. 200 Houston, TX 77034 http://www.L-Con.com	281-484-5266	
LIG Midstream Co. LLC 615 N. Upper Broadway, Ste. 1200 Corpus Christi, TX 78401	361-654-6510	

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Linde Process Plants, Inc. 6100 S. Yale, Ste. 1200 Tulsa, OK 74136 http://www.lppusa.com	918-477-1200	918-477-1100
LKS Midstream Consulting LLC 5960 West Parker Road #278 - 233 Plano, TX 75093 http://lksmidstream.com	469-443-0637	
Lockwood International 2209 N. Padre Island Dr. St. Y Corpus Christi, TX 78468 http://lockwoodint.com	361-815-8275	361-289-8839
Louisiana Valve Source, Inc. 101 Metals Dr. Youngsville, LA 70592 http://www.lavalve.com	337-856-9100	337-857-2969
M & J Valve 4150 South 100 East Ave., Suite 200W Tulsa, OK 74146	918-663-9595	
M Chemical Co. 850 Colorado Blvd Los Angeles, CA 90041 http://www.mchemical.com	323-254-3600	323-257-6968
M&H Enterprises, Inc. 19450 Hwy 240, #600 Houston, TX 77070 http://www.mhes.com/	713-974-3627	
Martin Energy Consultants P.O. Box 8064 The Woodlands, TX 77387	281-367-9401	
Master Corp. 1330 East 8th St., Suite 105 Odessa, TX 79761-4713 http://www.mastercorporation.com	432-580-0600	432-335-0600
Masters Process Equipment 26118 North IH-45 Spring, TX 77386 http://www.mastersprocess.com	281-367-5699	281-367-5685
McAfee & Taft 1717 S. Boulder Ave, Ste. 900 Tulsa, OK 74119 http://www.mcafeetaft.com	918-587-0000	
McJunkin Red Man Corporation P.O. Box 4395 Odessa, TX 79760	972-602-4075	
Mechnical Equipment, Inc. P.O. Box 1800 Midland, TX 79702	432-687-0601	
MEGTEC Systems Inc. 830 Prosper Road De Pere, WI 54115	920-339-2787	
MEI LLC 138 Canal Street, Suite 501 Pooler, GA 31322 http://www.mei-consult.com	912-355-8001	912-355-0065
MHBT, Inc. 8144 Walnut Hill Lane, 16th Floor Dallas, TX 75231	972-770-1655	
Michell Instruments Inc. 14915 Terra Point Cypress, TX 77429 http://www.michell.com/us	281-728-3982	

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MidCon Compression LLC P.O. Box 18881 Oklahoma City, OK 73154 http://www.midconcompression.com	405-935-4159	405-849-0003
Mid-States Supply 1716 Guinotte Ave. Kansas City, MO 64120 http://www.midcoonline.com	800-825-1410	816-842-3630
Midstream Energy Group, Inc. 10707 Corporate Drive, Ste 158 Stafford, TX 77477 http://www.midstreamenergygroup.com	281-277-5560	
Midway Laboratory Inc. 315 Main Street Taft, CA 93268 http://www.midwaylaboratory.com	661-765-2364	661-765-6920
MIRATECH Corp. 420 So. 145th East Ave. Tulsa, OK 74108	918-622-7077	918-622-3928
Mobile Analytical Labs Inc. P. O. Box 69210 Odessa, TX 79769	432-337-4744	
MODEC International Inc. 14741 Yorktown Plaza Houston, TX 77040 http://www.modec.com	281-529-8100	281-529-8102
Modern Project Services TJ Carmody Cedar Rapids, IA 52406 http://www.modernprojectservices.com	319-730-8030	319-364-8368
Monico Monitoring, Inc. 5527 Louetta Road, Ste. D Spring, TX 77380 http://www.monicoinc.com	281-350-8751	
Moore Control Systems Inc. 1435 Katy-Flewellen Katy, TX 77494 http://www.moore-control.com	281-392-7747	281-392-7727
Morrow Renewables LLC P.O. Box 61447 Midland, TX 79711 http://www.morrowrenewables.com	918-432-570-4200	
Movilab, S.A. de C.V. Paseo de Francia 163 piso 1 Naucalpan, Mexico 53120	525553442121 X102	
MSES Corrosion Products Division 609 West Main St. Clarksburg, WV 26302 http://www.msesproducts.com	304-624-9700	304-622-0981
Mueller Environmental Designs 7607 Wright Rd Houston, TX 77041 http://www.muellerenvironmental.com	832-300-1122	713-465-0997
Mustang Cat 12800 NW Freeway Houston, TX 77040	713-460-7238	
Nalco Chemical Co. 4500 S Lakeshore Drive Tempe, AZ 85282 http://www.nalco.com	630-305-1000	480-774-0185

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Network International 3555 Timmons Lane, Ste. 1200 Houston, TX 77027 http://www.networkintl.com	713-659-7500	713-850-0808
Neuman & Esser USA, Inc. 1502 East Summitry Circle Katy, TX 77449 http://www.neuman-esser.com	281-497-5113	281-497-5047
New Tech Global Ventures 202 Madison Square Colleyville, TX 76034	817-821-8107	
Nextteq LLC 8406 Benjamin Road, Ste. J Tampa, FL 33634 http://www.nextteg.com	877-312-2333	877-312-2444
Niagara Blower Heat Transfer Solutions 673 Ontario St Buffalo, NY 14207 http://www.niagarablower.com	716-875-2000	716-875-1077
Nicholas Consulting Group Inc. 600 N. Marienfeld, Suite 390 Midland, TX 79701 http://www.thencg.com	432-570-8093	432-683-1993
Norriseal 11122 West Little York St. Houston, TX 77041 http://www.norriseal.com	713-466-3552	713-896-7386
Norwood S&S, LLC 6415 Calle Lozano Dr. Houston, TX 77041-2559 http://www.NorwoodSS.com	281-558-2946	281-558-8405
Nova Molecular Technologies 1 Parker Place, Ste. 725 Janesville,, WI 53545	608-754-6682	
Oil & Gas Awards 60 A George Row London, SE164WA http://www.oilandgasawards.com	00121059 18471	
Omni Flow Computers, Inc. 12620 W. Airport Blvd., Ste. 100 Sugar Land, TX 77479 http://www.omniflow.com	281-240-6161	281-240-6162
Onsite Power Inc. 6525 S. Riviera Way Aurora, CO 80016	303-690-8486	
Optimized Gas Treating, Inc. P.O. Box 125 Clarita, OK 74535 http://www.ogtrt.com	580-428-3535	580-428-3535
Optimized Pipeline Solutions 59 Joshua Court Lake Jackson, TX 77566	979-583-8839	
Optimized Process Designs 25610 Clay Road Katy, TX 77493 http://www.opd-inc.com	281-371-7500	281-371-0132
Optimized Process Furnaces 3995 S Santa Fe Chanute, KS 66720 http://www.firedheater.com	620-431-1260	620-431-6631

Company& Address	Phone	Fax
Ortloff Engineers, Ltd. 415 W. Wall, Ste. 2000 Midland, TX 79701 http://www.ortloff.com	432-685-0277	
Pantechs Laboratories, Inc. 5915 50th Street Lubbock, TX 79424 http://www.pantechs.com	806-797-4325	806-797-4474
Paragon Field Services 500 Main St La Marque, TX 77568 http://www.paragontexas.com	409-935-6602	409-935-9361
Parker Hannifin Corp. P. O. Box 599 Oxford, MI 48371	248-628-6400	
PCL Industrial Construction Co. 15915 Katy Freeway, Ste. 300 Houston, TX 77094 http://www.pcl.com	281-249-8022	
PECOFacet 118 Washington Avenue Mineral Wells, TX 76068 http://www.pecofacet.com	940-325-2575	940-325-4622
Peerless Mfg. Co. 2930 West Sam Houston Parkway, Ste. 225 Houston, TX 77043 http://www.peerlessmfg.com	281-655-7800	
Pennwell Corp. 1455 West Loop S Houston, TX 77027 http://www.pennwell.com	713-963-6276	713-963-6285
Pentair Porous Media Corp. 4301 West Davis Conroe, TX 77304 http://www.pentair.com	936-788-1000	936-788-1220
Perry Gas Processors L.P. P.O. Box 13270 Odessa, TX 79768	432-332-0100	
Petral Consulting Company P.O. Box 42586 Houston, TX 77242 http://www.petral.com/		
Petrin Corporation 1405 Commercial Drive Port Allen, TX 70767 http://www.petrincorp.com	800-256-7876	225-343-0475
Petro-Canada America Lubricants Inc. 4120 S. Juniper Ave. Broken Arrow, OK 74011 http://www.lubricants.petro-canada.ca	918-451-5655	
Petronas TBG 83 KG Kuantan Klang, Selangor 41300 http://www.petronas.com.my	60323315348	
Plant Eng. Construction Pte. Ltd. 21 Shipyard Rd. Singapore, 628144	65-6268-9788	
Praxair Inc. 175 East Park Drive Tonawanda, NY 14151	716-879-2128	

Company& Address	Phone	Fax
Precision Flow Inc. P.O. Box 7137 Odessa, TX 79760	432-381-5131	
Prime Controls, LP 815 Office Park Circle Lewisville, TX 75057 http://www.prime-controls.com	972-221-4849	
Puffer Sweiven 4230 Greenbriar Drive Stafford, TX 77477 http://www.puffersweiven.com	281-240-2000	281-274-6438
Q.B. Johnson Manufacturing, Inc. 9000 S. Sunnylane Rd. Oklahoma City, OK 73189 http://www.qbjohnson.com	405-677-6676	405-670-3270
Q2 Technologies, LLC 14720 Highway 105 West, #200 Montgomery, TX 77356 http://www.q2technologies.com	936-588-2242	936-588-2298
QuantityWare GmbH Zeiloch 1b Bruchsal, 76646 http://www.quantityware.com	49 7251 982 3003	49 7251 982 3116
Questar Energy Services P. O. Box 1129 Rock Springs, WY 82902-1129	307-352-7292	
Quorum Business Solutions, Inc. 811 Main Street, Ste. 2000 Houston, TX 77002 http://www.qbsol.com	713-430-8601	713-430-8697
R&R Engineering Co., Inc. 12585 E. 61st St. Broken Arrow, OK 74012	918-252-2571	
Randall Gas Technologies 2 Riverway, Ste. 1300 Houston, TX 77056	713-375-8266	
Ranger Plant Constructional Company, Inc. 5851 E. Interstate 20 Abilene, TX 79601 http://www.rpccinc.com	325-677-2888	
Ref-Chem, L.P. 1128 S. Grandview Ave. Odessa, TX 79761 http://www.ref-chem.com	432-332-8531	432-332-3325
Regard Resources Co., Inc 555 Aero Dr. Shreveport, LA 71107 http://www.regardresources.com	318-425-2533	318-425-1014
REM Technology, Inc. 4306 Phil Street Bellaire, TX 77401 http://www.remtechnology.com	832-314-8255	
RES Energy Solutions 2010 McAllister Rd. Houston, TX 77092 http://www.res-co.com	832-310-1801	
Rexel Inc. 8042 Katy Freeway, Ste. 100 Houston, TX 77024 http://www.rexelusa.com	713-316-1700	713-686-8906

Company& Address	Phone	Fax
Rhine Ruhr Pty Ltd Unit 1, 10-30 West Circuit, Sunshine West Melbourne, Vi 3020 http://www.rhineruhr.com.au	61 3 9300 5000	61 3 9300 5001
Rino - K&K Compression, Ltd. 3302 Lilac Street Pasadena, TX 77505 http://www.rino-kk.com	281-487-3890	281-487-7472
River City Engineering 4830 Bob Billings Parkway, Suite 100B Lawrence, KS 66049 http://www.rivercityeng.com	785-842-4783	785-842-1450
RK Turbine Consultants 330 W. Government St. Pensacola, FL 32502	850-221-6029	
Robert R. Reis, Attorney-Mediator, P.C. P. O. Box 520954 Tulsa, OK 74114	918-742-2028	918-742-2028
Rotor-Tech Inc. 10613 Stebbins Circle Houston, TX 77379 http://www.rotor-tech.com	713-984-8900	713-984-9425
Royal Filter Mfg. Co., Inc. 4327 S. 4th Chickasha, OK 73018 http://www.royalfilter.com	405-224-0229	
S&B Engineers and Constructors, Ltd. 7825 Park Place Blvd. Houston, TX 77087	713-845-7850	
S&B Infrastructure, Ltd. 100 E. 15th St., #650 Fort Worth, TX 76102 http://www.sbinfra.com	817-820-0036	
Sagebrush Pipeline Equipment 8100 New Sapulpa Rd Tulsa, OK 74131 http://www.sagepipe.com	918-551-5600	918-224-8452
SAIC Energy, Environment, and Infrastructure One West Third, Ste. 200 Tulsa, OK 74103 http://www.saic.com/EEandI	918-599-4361	
Salof Refrigeration Co., Inc. 1150 Schwab Road New Braunfels, TX 78132 http://www.salofcompanies.com	830-625-1613	830-625-0778
Samuel Engineering Inc. 8450 E. Crescent Pkwy., Ste. 2300 Greenwood Village, CO 80111 http://www.samuelengineering.com	303-714-4840	
Saulsbury Industries Inc. 2951 E. Interstate 20 Odessa, TX 79766	432-366-3686	432-368-0061
Saxon Construction, Inc. 790 Brogdon Road Suwanee, GA 30024	770-271-2174	770-271-2176
SCFM Compression Systems, Inc. 3701 S. Maybelle Ave. Tulsa, OK 74107 http://www.scfm.com	918-663-1309	918-663-6140

Company& Address	Phone	Fax
Schwob Energy Services 2349 Glenda Lane Dallas, TX 75229 http://www.schwob.com	972-243-7674	
S-Con, Inc. 8326 Hwy 21 West Bryan, TX 77807	979-822-4445	
Scott Measurement Service Inc. P.O. Box 5247 Granbury, TX 76049 http://www.scottmeasurement.com	817-573-0036	817-573-0364
SEC Energy Products & Services L.P. 9523 Fairbanks N Houston Houston, TX 77064 http://www.sec-ep.com	281-890-9977	281-955-6346
Select Engineering, Inc. 1717 S. Boulder, Suite 600 Tulsa, OK 74119 http://www.select-engineering.com	918-592-1133	918-592-1134
Sep-Pro Systems, Inc. 11050 W. Little York, Bldg. K Houston, TX 77041 http://www.sepprosystems.com	832-243-7360	
Sepra-Chem Corporation 10975 Spur 248 Tyler, TX 75707 http://www.sepra-chem.com	903-566-1015	903-566-1094
SERO Pump Systems, Inc. 3727 Greenbriar Drive, Ste. 105 Stafford, TX 77477 http://www.seropumps.com/	281-242-8080	
Setec Astronomy, Inc. P.O. Box 6557 Tyler, TX 75711		903-312-9435
Shamrock Gas Analysis 1100 South Madden St. Shamrock, TX 79097 http://www.sgalab.com	806-256-3249	806-256-3159
Sherry Laboratories 2120 W. Willow St. Scott, LA 70583		
Simms Machinery International 2357 A Street Santa Maria, CA 93455 http://simmsmachineryinternational.com	805-349-2540	805-349-9959
SME Associates LLC 6715 Theall Rd. Houston, TX 77066	281-440-7350	
SME Products, LP 6715 Theall Rd. Houston, TX 77066	281-440-7353	
Smith & Burgess 5700 Northwest Central Drive, #301 Houston, TX 77092 http://www.smithburgess.com	713-082-2647	
Smithco Engineering, Inc. 6312 S 39th West Avenue Tulsa, OK 74132 http://www.smithco-eng.com	918-446-4406	918-445-2857
SNC-Lavalin E&C 9009 West Loop South, Suite 800 Houston, TX 77096-1719 http://www.snclavalin.com	713-667-9162	713-667-9241

Company& Address	Phone	Fax
Solutia - Therminol Heat Transfer Fluids 7710-T Cherry Park Dr #126 Houston, TX 77095 http://www.therminol.com	281-750-2661	207-213-3473
Southern Flow Companies, Inc. 5291 Hanselman Victoria, TX 77905 http://www.southernflow.com	361-575-4528	361-575-9512
Southern Heat Exchanger Services 12210 A US 90 East Houston, TX 77049	281-506-0934	
Spartan Engineering Inc. 10820 E. 45th Street, Ste. 100 Tulsa, OK 74146 http://www.spartan-eng.com	918-895-7666	
Specialty Process Equipment Corporation 6400 Hawes Road Humble, TX 77396 http://www.spec-pro.com	281-812-7732	281-852-7732
SpectraSensors Inc. 4333 W. Sam Houston Houston, TX 77043 http://www.spectrasensors.com	713-300-2719	713-856-6623
Spectrum-Prime Solutions, L.P. 24 E. Greenway Plaza, Ste. 1180 Houston, TX 77046 http://www.spectrumprime.com	713-589-6852	
SPL Inc. 8880 Interchange Drive Houston, TX 77054 http://www.spl-inc.com	713-660-0901	713-660-6035
Strategic Automation Services LLC 16203 Park Row Road, Ste. 140 Houston, TX 77084	281-945-8900	
Strategy Engineering & Consulting, LLC 15995 N. Barkers Landing, Ste. 200 Houston, TX 77079 http://www.strategyeng.com	281-657-7012	
Subsurface Technology, Inc. 6925 Portwest Dr., Suite 110 Houston, TX 77024 http://www.subsurfacegroup.com	713-880-4640	713-880-3248
SulfaTreat, A Division of M-I LLC 17998 Chesterfield Airport Road, Suite 215 Chesterfield, MO 63005	800-726-7687	
Sulfur Operation Support P.O. Box 1770 Ocean Springs, MS 39566		
Sulzer Chemtech 8505 E. North Belt Drive Humble, TX 77396	281-216-8562	
Sundyne LLC 14845 West 64th Ave. Arvada, CO 80007 http://www.sundyne.com	303-425-0800	303-940-2911
Sunland Construction Inc. 315 Country Drive Delcambre, LA 70528 http://www.sunlandconstruction.com	337-685-2167	337-685-2168

Company& Address	Phone	Fax
Superheat FGH Services, Inc. 680 Industrial Park Drive Evans, GA 30809 http://www.superheatfgh.com	706-790-5353	706-790-3383
Superior Specialty Gas Services, Inc. 1102 W. 36th St. N. Tulsa, OK 74127 http://www.supspecgas.com	918-592-0081	918-592-0095
Swagelok Oklahoma 9421 E. 54th St. Tulsa, OK 74145 http://www.swagelok.com/tulsa	918-258-8661	918-258-1262
T.F. Hudgins Inc. P.O. Box 920946 Houston, TX 77292-0946	713-682-3651	
Taylor Forge Engineered Systems 308 N. Iron Street Paola, KS 66071	913-294-5331	
TEA 7580 East 151st Street Bixby, OK 74008 http://www.teaeng.com	918-394-9444	
Teague Nail and Perkins, Inc. 1100 Macon Street Fort Worth, TX 76102	817-665-7169	
Tetra Technologies Inc. 24955 I 45 North The Woodlands, TX 77380 http://www.tetratec.com	281-364-4339	
Texas Turbine, Inc. 624 Profit St Azle, TX 76020 http://www.txturbine.com	817-444-5528	817-444-3925
Texas Welders Supply 10210 I-45 North Houston, TX 77037	281-880-4392	
The Arrington Corporation P.O. Box 3128 Flint, TX 75762 http://www.arringtoncompanies.com	903-894-6157	903-894-7428
The PROS Company 601 Texas Avenue Lubbock, TX 79401 http://www.thePROSco.com	806-749-7761	806-749-7762
Thomas Petroleum Ltd. P.O. Box 1876 Victoria, TX 77902	361-573-7662x123	
Thomas Russell Co. 7050 S Yale, Ste 210 Tulsa, OK 74136 http://www.thomasrussellco.com	918-481-5682	918-481-7427
Thurmond-McGlothlin, Inc. 1428 N. Banks Pampa, TX 79066 http://www.tm-ems.com	806-665-5700	806-665-2632
Tiger Tower Services 3012 Farrell Road Houston, TX 77073 http://www.tigertowerservices.com	281-951-2500	281-951-2520
Tomcej Engineering Inc. P.O. Box 1274 Station Main Edmonton, Al T5J 2M8 http://www.tomcej.com	780-483-0248	780-483-0248

Company& Address	Phone	Fax
Torrent Energy Services 5950 Berkshire Lane Dallas, TX 75225 http://www.torrentenergyservices.com	281-450-4000	
Total Energy Corp. 100 W. Airport Road Stillwater, OK 74075 http://www.totalenergy.com	405-253-4728	405-743-2900
Toyo Engineering Corp. 2-8-1, Akanehama Narashino-shi, Chiba, 275-0024 http://www.toyo-eng.co.jp/	81 47 451 1111	81 47 454 1800
TRC Companies, Inc. 7761 Shaffer Parkway, Ste. 100 Littleton, CO 80127 http://www.trcsolutions.com	303-395-4021	
Trimeric Corp. P.O. Box 826 Buda, TX 78610		512-295-8118
Trinity Consultants 12770 Merit Drive, Ste. 900 Dallas, TX 75251 http://www.trinityconsultants.com	972-661-8100	
Trinity Containers, LLC 2525 Stemmons Freeway Suite 520 Dallas, TX 75207-2401 http://www.trinitycontainers.com	888-558-8529	214-589-8553
Trinity Contractors 803 Old Justin Road Argyle, TX 76226	940-240-5800	
TriStar Global Energy Solutions 12600 N. Featherwood, Ste. 330 Houston, TX 77034 http://www.tristarges.com	713-463-9200	713-463-9216
TriTex Technologies Inc. 5339 Alpha Rd, Suite 215 Dallas, TX 75240 http://www.tritextech.com	972-233-2536	972-233-5160
Troy Construction Co. 8521 McHard Road Houston, TX 77053	281-437-6214	
United Shutdown Safety 629 Howard Ave., Bldg. A Deer Park, TX 77536	281-241-1740	
United Steel Structures, Inc. 1330 Enclave Parkway - Suite 400 Houston, TX 77077 http://www.ussi.com	281-496-1300	
United/Wells Inc. P. O. Box 4575 Odessa, TX 79760	915-362-2361	
Univar USA Inc. 11235 FM 529 RD. Houston, TX 77546 http://www.univarusa.com/oil.htm	214-632-4430	713-286-6965
Upstream Development and Engineering, Inc. 11767 Katy FWY, Suite 215 Houston, TX 77079 http://www.upstreamdne.com	281-752-7754	281-752-4559

Company& Address	Phone	Fax
URS 7800 E. Union Ave. Denver, CO 80237 http://www.urs.com	303-843-2000	303-843-2208
USA Environment, L.P. 10234 Lucore Street Houston, TX 77017 http://www.usaenviro.com	832-488-4088	
Valerus 919 Milam, Ste. 1000 Houston, TX 77002 http://www.VALERUS-co.com	713-744-6100	713-744-6101
Van Gas Technologies 2950 Mechanics Street Lake City, PA 16423 http://www.vangastech.com	814-774-2631	814-774-0778
Vanco Equipment Co. 7033 E. 40th Street Tulsa, OK 74145	918-627-1920	918-627-6742
Vanderpool Pipeline Engineers Inc. P.O. Box 590 Littleton, CO 80160 http://www.vpeinc.com	303-798-0275	303-484-3880
Vanson Engineering Co. 1240 N. Van Buren St., Ste. 212 Anaheim, CA 92807	714-630-3344	714-630-0384
Vapor Point, LLC P.O. Box 1239 La Porte, TX 77572 http://www.vaporpoint.net	281-867-8186	281-867-8191
Vinson Process Controls 2747 Highpoint Oaks Drive Lewisville, TX 75067 http://www.vinsonprocess.com	972-459-8200	972-459-8316
Vintrol Inc. 5325 SW 36th St. Oklahoma City, OK 73179 http://www.vintrol.com	405-261-0770	
Virtual Materials Group P.O. Box 786 Fulshear, TX 77441 http://www.virtualmaterials.com	281-346-1200	281-346-0288
Wagner Power Systems 4000 Osuna Road NE Albuquerque, NM 87109 http://www.wagnerpower.com	505-345-8411	505-344-0397
Waid Environmental 10800 Pecan Park Blvd., Ste. 300 Austin, TX 78750	512-255-9999	
Welker, Inc. 13839 West Bellfort Sugar Land, TX 77498 http://www.welkereng.com	281-491-2331	281-491-8344

Company& Address	Phone	Fax
Wellsite Compressor & Equipment Co. 3600 Bent Cedar Trail Edmond, OK 73034 http://www.wellsitecompressor.com	405-282-8590	405-282-8591
Western Filter Co., Inc. 10702 E. 11th Street Tulsa, OK 74128 http://www.westernfilterco.com	918-949-4455	918-949-4459
Whitlow Professional Services 22164 MCH Rd., Ste. A Mandeville, LA 70471 http://www.whitlowps.com	985-893-1100	
Willbros Group 4400 Post Oak Parkway, Ste. 1000 Houston, TX 77036 http://www.willbros.com	713-403-8000	
Wilson Midstream Services, LLC 2807 Allen Street, #343 Dallas, TX 75204	214-774-9000	
Wilson-Mohr 12610 W Airport Blvd #100 Sugar Land, TX 77478 http://www.wilsonmohr.com	281-295-8850	281-295-8870
WinSim Inc. 8653 FM 2759 Rd. Richmond, TX 77469 http://www.winsim.com	281-565-6700	281-565-7593
Wood Group Mustang, Inc. 16001 Park Ten Place Houston, TX 77077 http://www.mustangeng.com	713-215-8000	281-206-1678
Wood Group PSN 17000 Katy Frwy., Ste. 150 Houston, TX 77094	281-647-8413	281-398-1734
Worley Parsons Resources & Energy 125 West Huntington Dr. Arcadia, CA 91007	626-294-3558	
York Process Systems 5692 E. Houston St. San Antonio, TX 78220 http://www.johnsoncontrols.com	210-661-9191	210-662-6591
ZAP Engineering & Construction Services 333 S. Allison Pkwy., Ste 100 Lakewood, CO 80226 http://www.zapecs.com	303-565-5533	
Zeeco 22151 East 91st Street Broken Arrow, OK 74014	281-345-4110	
Zeochem 1600 West Hill St. Louisville, KY 40210 http://www.zeochem.com	502-634-7600	502-634-8133

Classification of Members

Services

Gas Processors Suppliers Association

6526 East 60th Street
Tulsa, Oklahoma 74145
Phone: 918-493-3872
Fax: 918-493-3875
Email: gpsa@GPAglobal.org
http://gpsa.GPAglobal.org

The following is a listing of GPSA member companies classified by the type of services that they provide to the industry.

COMPLIANCE - AUDITING

CH2M Hill
Contek Solutions LLC
EnerSsys Corporation
Geolex, Inc.
Gulf Interstate Engineering
HJ Baker, PE
Joule Processing LLC.
M&H Enterprises, Inc.
McAfee & Taft
MEI LLC
Nalco Chemical Co.
QuantityWare GmbH
Select Engineering, Inc.
Southern Flow Companies, Inc.
SPL Inc.
TRC Companies, Inc.
Trinity Consultants

COMPLIANCE - CRITICAL INCIDENT/EMERGENCY RESPONSE

Air Products and Chemicals
Conestoga-Rovers & Associates
Heath Consultants Inc.
QuantityWare GmbH
Select Engineering, Inc.
USA Environment, L.P.

COMPLIANCE - EMISSIONS TESTING

Aeros Environmental, Inc.
Anguil Environmental
Catalytic Products International, Inc.
Conestoga-Rovers & Associates
Croft Production Systems, Inc.
Federal Services LLC
FESCO, Ltd
Gly-Tech Services
Heath Consultants Inc.
SPL Inc.
TRC Companies, Inc.

COMPLIANCE - ENVIRONMENTAL SERVICES

Air Products and Chemicals
Anguil Environmental
Catalytic Combustion Corporation
Catalytic Products International, Inc.
CEI Engineering Associates
CH2M Hill
Conestoga-Rovers & Associates
Contek Solutions LLC
Edge Engineering & Science
Freese and Nichols, Inc.
G2 Partners, LLC
Geolex, Inc.
Gly-Tech Services
M&H Enterprises, Inc.
McAfee & Taft
MIRATECH Corp.
MSES Corrosion Products Division
Nalco Chemical Co.
Pantechs Laboratories, Inc.
SAIC Energy, Environment, and Infrastructure
SPL Inc.
TRC Companies, Inc.
Trinity Consultants
United Steel Structures, Inc.
USA Environment, L.P.
Vapor Point, LLC
Willbros Group
Wood Group Mustang, Inc.

COMPLIANCE - LEAK DETECTION SERVICES

Air Products and Chemicals
Conestoga-Rovers & Associates
Contek Solutions LLC
EnerSsys Corporation
Geolex, Inc.
Heath Consultants Inc.
SPL Inc.
Thurmond-McGlothlin, Inc.
Trinity Consultants
Willbros Group

COMPLIANCE - LEGAL SERVICES

ENGlobal Corporation
McAfee & Taft
Robert R. Reis, Attorney-Mediator, P.C.
SPL Inc.

COMPLIANCE - SAFETY CONSULTANT

Air Products and Chemicals
Conestoga-Rovers & Associates
Contek Solutions LLC
Elkhorn Holdings Inc
Federal Services LLC
G2 Partners, LLC
Gly-Tech Services
GWD
HJ Baker, PE
M&H Enterprises, Inc.
MEI LLC
MSES Corrosion Products Division
Nalco Chemical Co.
Select Engineering, Inc.
Toyo Engineering Corp.
TRC Companies, Inc.
Willbros Group
Wood Group Mustang, Inc.

COMPLIANCE - SECURITY

Cimation
GWD
McAfee & Taft
TRC Companies, Inc.

CONSULTING - COMPUTER SYSTEMS

Analytical Instruments Corporation
Barry D. Payne & Associates, Inc.
Cimation
Conestoga-Rovers & Associates
Entero Corporation
eSimulation Inc.
Federal Services LLC
GWD
M&H Enterprises, Inc.
Modern Project Services
Moore Control Systems Inc.
Puffer Sweiven
QuantityWare GmbH
Quorum Business Solutions, Inc.
Select Engineering, Inc.
Toyo Engineering Corp.
Wilson-Mohr
Wood Group Mustang, Inc.

CONSULTING - EXPERT WITNESS

Applied Consultants, Inc.
Baker & O'Brien, Inc.
Coastal Flow Measurement, Inc.
Conestoga-Rovers & Associates
Geolex, Inc.
Gulsby Engineering Inc.
HPF Consultants, Inc.
J. H. Foglietta Consulting LLC
John M. Campbell & Company
Optimized Gas Treating, Inc.
Robert R. Reis, Attorney-Mediator, P.C.
Samuel Engineering Inc.
Select Engineering, Inc.
SPL Inc.
The Arrington Corporation
Thurmond-McGlothlin, Inc.
TRC Companies, Inc.
Trinity Consultants
TriTex Technologies Inc.
Vanson Engineering Co.

CONSULTING - FORENSIC ENGINEERING

Applied Consultants, Inc.
Baker & O'Brien, Inc.
Conestoga-Rovers & Associates
Geolex, Inc.
John M. Campbell & Company
Modern Project Services
The PROS Company

CONSULTING - CORROSION

Applied Consultants, Inc.
Conestoga-Rovers & Associates
Consulting and Field Services
Federal Services LLC
Gly-Tech Services
Gulf Coast Chemical, LLC
Gulf Interstate Engineering
GWD
International Oil & Gas Consultants Pte, Ltd.
John M. Campbell & Company
Modern Project Services
MSES Corrosion Products Division

Nalco Chemical Co.
Toyo Engineering Corp.
Troy Construction Co.
Willbros Group

CONSULTING - STRATEGY PLANNING

Baker & O'Brien, Inc.
BENTEK Energy LLC
Conestoga-Rovers & Associates
Contek Solutions LLC
eSimulation Inc.
G2 Partners, LLC
Geolex, Inc.
Gulf Interstate Engineering
Gulsby Engineering Inc.
GWD
HPF Consultants, Inc.
J MAR & Associates
J. H. Foglietta Consulting LLC
John M. Campbell & Company
LKS Midstream Consulting LLC
M&H Enterprises, Inc.
MIRATECH Corp.
Modern Project Services
Nalco Chemical Co.
QuantityWare GmbH
The Arrington Corporation
TRC Companies, Inc.
TriTex Technologies Inc.
Willbros Group

DISMANTLE, SURPLUS EQUIPMENT

ARC Energy Equipment
Elkhorn Holdings Inc
Gas Technology Corporation
Gly-Tech Services
Gregory Gas Services, LLC
GWD
HETSCO, Inc.
M&H Enterprises, Inc.
Modern Project Services
Nicholas Consulting Group Inc.
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Saxon Construction, Inc.
SCFM Compression Systems, Inc.

ENGINEERING - PROCUREMENT AND CONSTRUCTION

Air Products and Chemicals
Allied Equipment
AMCS Corporation
Applied Consultants, Inc.
Barry D. Payne & Associates, Inc.
Bowden Construction Co.
Brahma Group Inc.
Catamount Constructors
CB&I
CH2M Hill
Cimation
Conestoga-Rovers & Associates
Croft Automation LLC
Cummings Electrical, Inc.
Elkhorn Holdings Inc
EMD, Inc.
ENGlobal Corporation
EPC Inc.
EXTERRAN
Fagen Inc.
FairFax Operations, LLC
Freese and Nichols, Inc.
Gas Corporation of America
Global Process Systems SDN BHD
Gulf Interstate Engineering
Gulsby Engineering Inc.
Halker Consulting, LLC
Hunt, Guillot & Associates
J.W. Williams Inc.,a Flint Energy Services Co.
JGC Corp.
Joule Processing LLC.
KBR, Inc.
L-Con, Inc. Engineers/Constructors
Linde Process Plants, Inc.
M&H Enterprises, Inc.
Master Corp.
MEI LLC
MIRATECH Corp.
MODEC International Inc.
Modern Project Services
Moore Control Systems Inc.
Nicholas Consulting Group Inc.
Optimized Process Designs
Paragon Field Services
PCL Industrial Construction Co.
Petrin Corporation
Ref-Chem, L.P.
Regard Resources Co., Inc
SAIC Energy, Environment, and Infrastructure
Salof Refrigeration Co., Inc.
Samuel Engineering Inc.
Saulsbury Industries Inc.
Saxon Construction, Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
SNC-Lavalin E&C
Sunland Construction Inc.
Thomas Russell Co.
Toyo Engineering Corp.
TRC Companies, Inc.
Troy Construction Co.
Upstream Development and Engineering, Inc.
URS
Valerus

Vanson Engineering Co.
Whitlow Professional Services
Willbros Group
Wilson-Mohr
Wood Group Mustang, Inc.
Wood Group PSN

ENGINEERING - DRAFTING

Air Products and Chemicals
Allied Equipment
Applied Consultants, Inc.
CB&I
CEI Engineering Associates
CH2M Hill
Conestoga-Rovers & Associates
Croft Automation LLC
EMD, Inc.
ENGlobal Corporation
EPC Inc.
EXTERRAN
FairFax Operations, LLC
Freese and Nichols, Inc.
G2 Partners, LLC
Gas Technology Corporation
Gulf Interstate Engineering
Gulsby Engineering Inc.
GWD
Halker Consulting, LLC
Harris Group Inc
HPF Consultants, Inc.
Hunt, Guillot & Associates
JGC Corp.
Joule Processing LLC.
L-Con, Inc. Engineers/Constructors
Linde Process Plants, Inc.
M&H Enterprises, Inc.
Master Corp.
MEI LLC
Modern Project Services
Moore Control Systems Inc.
MSES Corrosion Products Division
Nicholas Consulting Group Inc.
Optimized Process Designs
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Sagebrush Pipeline Equipment
SAIC Energy, Environment, and Infrastructure
Salof Refrigeration Co., Inc.
Samuel Engineering Inc.
Saulsbury Industries Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
Simms Machinery International
SNC-Lavalin E&C
Thomas Russell Co.
Toyo Engineering Corp.
TRC Companies, Inc.
TriTex Technologies Inc.
Upstream Development and Engineering, Inc.
URS
Vanson Engineering Co.
Welker, Inc.
Whitlow Professional Services
Willbros Group
Wood Group Mustang, Inc.
ZAP Engineering & Construction Services

ENGINEERING - PIPELINE

Air Products and Chemicals
Applied Consultants, Inc.
Bechtel
CB&I
CEI Engineering Associates
CH2M Hill
Conestoga-Rovers & Associates
Croft Automation LLC
Elkhorn Holdings Inc
EMD, Inc.
EXTERRAN
Fabreeka International
Freese and Nichols, Inc.
G2 Partners, LLC
Global Process Systems SDN BHD
Gulf Interstate Engineering
GWD
Halker Consulting, LLC
HPF Consultants, Inc.
Hunt, Guillot & Associates
JGC Corp.
Joule Processing LLC.
KBR, Inc.
M&H Enterprises, Inc.
Master Corp.
MEI LLC
Modern Project Services
MSES Corrosion Products Division
Nalco Chemical Co.
Nicholas Consulting Group Inc.
Sagebrush Pipeline Equipment
Samuel Engineering Inc.
Select Engineering, Inc.
SNC-Lavalin E&C
Toyo Engineering Corp.
TRC Companies, Inc.
TriTex Technologies Inc.
URS
Vanson Engineering Co.
Whitlow Professional Services
Willbros Group
Wood Group Mustang, Inc.
ZAP Engineering & Construction Services

ENGINEERING - PROCESS

Air Products and Chemicals
Allied Equipment

AMCS Corporation
Analytical Instruments Corporation
Applied Consultants, Inc.
Atlas Copco Gas and Process
Bechtel
CB&I
CEI Engineering Associates
CH2M Hill
Conestoga-Rovers & Associates
Credence Gas Services LLC
Croft Automation LLC
Detechtion Technologies
Dickson Process Systems Ltd.
EMD, Inc.
EnerSsys Corporation
ENGlobal Corporation
EPC Inc.
EXTERRAN
Fagen Inc.
FairFax Operations, LLC
Freese and Nichols, Inc.
G2 Partners, LLC
Gas Technology Corporation
GEA Refrigeration North America Inc.
Geolex, Inc.
Global Process Systems SDN BHD
Gly-Tech Services
Gulf Interstate Engineering
Gulsby Engineering Inc.
GWD
Halker Consulting, LLC
Harris Group Inc
HPF Consultants, Inc.
Hunt, Guillot & Associates
International Oil & Gas Consultants Pte, Ltd.
J. H. Foglietta Consulting LLC
JGC Corp.
Johnson Matthey Catalysts
Jonell, Inc
Joule Processing LLC.
KBR, Inc.
KW International
L-Con, Inc. Engineers/Constructors
Linde Process Plants, Inc.
LKS Midstream Consulting LLC
M Chemical Co.
M&H Enterprises, Inc.
Master Corp.
MEI LLC
Modern Project Services
MSES Corrosion Products Division
Mueller Environmental Designs
Nalco Chemical Co.
Nicholas Consulting Group Inc.
Optimized Process Designs
Ortloff Engineers, Ltd.
Prime Controls, LP
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Regard Resources Co., Inc
Rhine Ruhr Pty Ltd
River City Engineering
SAIC Energy, Environment, and Infrastructure
Samuel Engineering Inc.
Saulsbury Industries Inc.
SCFM Compression Systems, Inc.
Select Engineering, Inc.
SNC-Lavalin E&C
Specialty Process Equipment Corporation
The Arrington Corporation
Thomas Russell Co.
Tomcej Engineering Inc.
Toyo Engineering Corp.
TriTex Technologies Inc.
Upstream Development and Engineering, Inc.
URS
Vanson Engineering Co.
Welker, Inc.
Whitlow Professional Services
Willbros Group
WinSim Inc.
Wood Group Mustang, Inc.
Wood Group PSN
ZAP Engineering & Construction Services
Zeochem

FACILITIES, EQUIPMENT

Aeon PEC
Air Products and Chemicals
Allied Equipment
AMCS Corporation
ARC Energy Equipment
Brahma Group Inc.
Cameron Valves and Measurement
CH2M Hill
Credence Gas Services LLC
Dew Point Control LLC
Dickson Process Systems Ltd.
Elkhorn Holdings Inc
EMD, Inc.
EXTERRAN
Fabreeka International
Gas Corporation of America
Gas Equipment Company, Inc.
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Compressor, LP
Global Process Systems SDN BHD
Gregory Gas Services, LLC
Gulsby Engineering Inc.
GWD
Halker Consulting, LLC
Hammco Inc.
Harris Group Inc
HPF Consultants, Inc.

J.W. Williams Inc.,a Flint Energy Services Co.
JGC Corp.
Joule Processing LLC.
KW International
Linde Process Plants, Inc.
Masters Process Equipment
Modern Project Services
Mueller Environmental Designs
Niagara Blower Heat Transfer Solutions
Nicholas Consulting Group Inc.
Optimized Process Furnaces
Peerless Mfg. Co.
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Regard Resources Co., Inc
River City Engineering
Rotor-Tech Inc.
SAIC Energy, Environment, and Infrastructure
Salof Refrigeration Co., Inc.
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
Sepra-Chem Corporation
Smithco Engineering, Inc.
SNC-Lavalin E&C
Specialty Process Equipment Corporation
SPL Inc.
Texas Turbine, Inc.
Thomas Russell Co.
Thurmond-McGlothlin, Inc.
Toyo Engineering Corp.
Upstream Development and Engineering, Inc.
URS
Valerus
Vanson Engineering Co.
Wagner Power Systems
Welker, Inc.
Willbros Group

GAS COMPRESSION - LEASING

EXTERRAN
Gas Technology Corporation
J-W Power Company
MidCon Compression LLC
MODEC International Inc.
SEC Energy Products & Services L.P.
Valerus

GAS COMPRESSION - REPAIR

Air Products and Chemicals
Brahma Group Inc.
Cameron Compression Systems
Cameron Valves and Measurement
Elkhorn Holdings Inc
Elliott Group
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Compressor, LP
J-W Power Company
L.A. Turbine
Neuman & Esser USA, Inc.
SEC Energy Products & Services L.P.
Simms Machinery International
The PROS Company
Valerus
Wagner Power Systems
Wellsite Compressor & Equipment Co.
Willbros Group

GAS COMPRESSION - SALES

A G Equipment Company
Air Products and Chemicals
Cameron Compression Systems
Cameron Valves and Measurement
Elliott Group
EXTERRAN
FES-Southwest, Inc.
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Compressor, LP
Global Process Systems SDN BHD
Guild Associates, Inc.
International Oil & Gas Consultants Pte, Ltd.
J-W Power Company
L.A. Turbine
MidCon Compression LLC
Neuman & Esser USA, Inc.
Rino - K&K Compression, Ltd.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Specialty Process Equipment Corporation
Valerus
Vanco Equipment Co.
Wellsite Compressor & Equipment Co.
York Process Systems

INSPECTIONS, TESTING, ANALYSIS - GAS CONTAMINATION TESTING

Aeros Environmental, Inc.
Analytical Instruments Corporation
Applied Consultants, Inc.
Conestoga-Rovers & Associates
Consulting and Field Services
Gas Analytical Solutions, Inc.
Intertek
Modern Project Services
Pantechs Laboratories, Inc.
PECOFacet
Scott Measurement Service Inc

SPL Inc.
Willbros Group

INSPECTIONS, TESTING, ANALYSIS - GENERAL

Aeros Environmental, Inc.
Air Products and Chemicals
Analytical Instruments Corporation
Applied Consultants, Inc.
Conestoga-Rovers & Associates
Consulting and Field Services
DBR Technology Center, Div. Schlumberger
Elkhorn Holdings Inc
GEA Refrigeration North America Inc.
Geolex, Inc.
Gulf Interstate Engineering
Heath Consultants Inc.
HPF Consultants, Inc.
Hunt, Guillot & Associates
Intertek
Modern Project Services
MSES Corrosion Products Division
Nalco Chemical Co.
Pantechs Laboratories, Inc.
SCFM Compression Systems, Inc.
Scott Measurement Service Inc
Simms Machinery International
SNC-Lavalin E&C
Southern Flow Companies, Inc.
SPL Inc.
Texas Turbine, Inc.
Thurmond-McGlothlin, Inc.
URS
Willbros Group
Zeochem

INSPECTIONS, TESTING, ANALYSIS - PIPELINE

Aeros Environmental, Inc.
Air Products and Chemicals
Analytical Instruments Corporation
Applied Consultants, Inc.
CEI Engineering Associates
Conestoga-Rovers & Associates
Elkhorn Holdings Inc
FESCO, Ltd
G2 Partners, LLC
Gulf Interstate Engineering
GWD
HPF Consultants, Inc.
Hunt, Guillot & Associates
M&H Enterprises, Inc.
Modern Project Services
MSES Corrosion Products Division
Nalco Chemical Co.
Southern Flow Companies, Inc.
SPL Inc.
Troy Construction Co.
Willbros Group

OPERATION, MAINTENANCE, RELIABILITY - ANALYTICAL LABORATORIES

Analytical Instruments Corporation
Diablo Analytical Inc.
EXTERRAN
FESCO, Ltd
John M. Campbell & Company
Midway Laboratory Inc.
MSES Corrosion Products Division
Nalco Chemical Co.
Pantechs Laboratories, Inc.
Scott Measurement Service Inc
Shamrock Gas Analysis
Southern Flow Companies, Inc.
SPL Inc.
Thurmond-McGlothlin, Inc.
Willbros Group

OPERATION, MAINTENANCE, RELIABILITY - FAILURE ANALYSIS

Applied Consultants, Inc.
Conestoga-Rovers & Associates
Gas Technology Corporation
John M. Campbell & Company
M&H Enterprises, Inc.
MSES Corrosion Products Division
Nalco Chemical Co.
Neuman & Esser USA, Inc.
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
Simms Machinery International
SNC-Lavalin E&C
Texas Turbine, Inc.
The PROS Company
Troy Construction Co.
Whitlow Professional Services

OPERATION, MAINTENANCE, RELIABILITY - INSPECTIONS

Aeon PEC
Applied Consultants, Inc.
Conestoga-Rovers & Associates
Consulting and Field Services
Eaton Metal Products Company
GWD
HETSCO, Inc.
Hunt, Guillot & Associates
John M. Campbell & Company
KW International
L.A. Turbine
M&H Enterprises, Inc.
Modern Project Services
Nalco Chemical Co.
Neuman & Esser USA, Inc.
Paragon Field Services

Ref-Chem, L.P.
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
SNC-Lavalin E&C
Troy Construction Co.
Whitlow Professional Services
Willbros Group

OPERATION, MAINTENANCE, RELIABILITY - INSULATION, PAINTING

Elkhorn Holdings Inc
Gas Technology Corporation
Modern Project Services
Petrin Corporation
Sunland Construction Inc.

OPERATION, MAINTENANCE, RELIABILITY - MACHINING AND REPAIR

Air Products and Chemicals
Atlas Copco Gas and Process
Best PumpWorks
Elkhorn Holdings Inc
Elliott Group
Gas Technology Corporation
HETSCO, Inc.
KW International
Louisiana Valve Source, Inc.
Modern Project Services
Neuman & Esser USA, Inc.
SCFM Compression Systems, Inc.
Simms Machinery International
SPL Inc.
Wagner Power Systems

OPERATION, MAINTENANCE, RELIABILITY - MEASUREMENT

Analytical Systems International
Cameron Valves and Measurement
Coastal Flow Measurement, Inc.
Detechtion Technologies
Diablo Analytical Inc.
Elkhorn Holdings Inc
Fluenta Inc.
GWD
Heath Consultants Inc.
Invensys-Foxboro
Louisiana Valve Source, Inc.
Modern Project Services
Neuman & Esser USA, Inc.
Omni Flow Computers, Inc.
Sagebrush Pipeline Equipment
Samuel Engineering Inc.
SPL Inc.
Thurmond-McGlothlin, Inc.
Welker, Inc.

OPERATION, MAINTENANCE, RELIABILITY - PERFORMANCE ANALYSIS

Air Products and Chemicals
AMCS Corporation
Analytical Instruments Corporation
Applied Consultants, Inc.
Baker & O'Brien, Inc.
CECA Molecular Sieves
Detechtion Technologies
EMD, Inc.
eSimulation Inc.
FairFax Operations, LLC
Gas Technology Corporation
Gly-Tech Services
GWD
John M. Campbell & Company
L.A. Turbine
M&H Enterprises, Inc.
Modern Project Services
Neuman & Esser USA, Inc.
Ortloff Engineers, Ltd.
Pantechs Laboratories, Inc.
River City Engineering
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
Simms Machinery International
SNC-Lavalin E&C
Texas Turbine, Inc.
Toyo Engineering Corp.
Welker, Inc.
Whitlow Professional Services
Wood Group Mustang, Inc.

OPERATION, MAINTENANCE, RELIABILITY - SERVICES

Aeon PEC
Air Products and Chemicals
Allied Equipment
Atlas Copco Gas and Process
Baker & O'Brien, Inc.
Bechtel
Brahma Group Inc.
Cameron Compression Systems
Cameron Valves and Measurement
Catalytic Products International, Inc.
CH2M Hill
Clary E&I Services, LLC
Elkhorn Holdings Inc
Elliott Group
EMD, Inc.
eSimulation Inc.
FairFax Operations, LLC
Federal Services LLC
Gas Technology Corporation
Gly-Tech Services
Gregory Gas Services, LLC
GWD

HETSCO, Inc.
John M. Campbell & Company
M&H Enterprises, Inc.
Mid-States Supply
Modern Project Services
Mueller Environmental Designs
Nalco Chemical Co.
Neuman & Esser USA, Inc.
Paragon Field Services
SCFM Compression Systems, Inc.
Shamrock Gas Analysis
SNC-Lavalin E&C
Sunland Construction Inc.
URS
USA Environment, L.P.
Valerus
Welker, Inc.
Willbros Group
Wood Group PSN

PROCESS CONTROLS - INSTRUMENT AND ELECTRICAL CONSTRUCTION

Allied Equipment
Analytical Instruments Corporation
Analytical Systems International
Barry D. Payne & Associates, Inc.
Bechtel
Brahma Group Inc.
Buffalo Gap Instrumentation & Electrical
CB&I
Clary E&I Services, LLC
Coastal Flow Measurement, Inc.
Conestoga-Rovers & Associates
Croft Automation LLC
Cummings Electrical, Inc.
Detector Electronics Corp.
Elkhorn Holdings Inc
EMD, Inc.
EnerSsys Corporation
ENGlobal Corporation
F.W. Murphy
Fagen Inc.
Fisher Controls
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
GWD
Halker Consulting, LLC
Invensys-Foxboro
JGC Corp.
Kenny Electric
LCM Industries, Inc.
Linde Process Plants, Inc.
Master Corp.
MEI LLC
Modern Project Services
Moore Control Systems Inc.
MSES Corrosion Products Division
Nicholas Consulting Group Inc.
Norriseal
Optimized Process Designs
PCL Industrial Construction Co.
Prime Controls, LP
Salof Refrigeration Co., Inc.
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
Select Engineering, Inc.
SPL Inc.
Sunland Construction Inc.
Thomas Russell Co.
TriTex Technologies Inc.
Vinson Process Controls
Willbros Group
Wilson-Mohr
Wood Group Mustang, Inc.

PROCESS CONTROLS - LICENSED PROCESSES

Air Products and Chemicals
Allied Equipment
Barry D. Payne & Associates, Inc.
Bechtel
CB&I
Conestoga-Rovers & Associates
EMD, Inc.
EXTERRAN
GEA Refrigeration North America Inc.
Prime Controls, LP
Salof Refrigeration Co., Inc.
Vinson Process Controls

TECHNOLOGY - LNG PROCESSES

Air Products and Chemicals
AMCS Corporation
Atlas Copco Gas and Process
Bechtel
Cameron Valves and Measurement
CB&I
Chart Energy & Chemicals, Inc.
Elliott Group
EXTERRAN
Gas Corporation of America
Global Process Systems SDN BHD
Guild Associates, Inc.
International Oil & Gas Consultants Pte, Ltd.
J. H. Foglietta Consulting LLC
JGC Corp.
John M. Campbell & Company
KBR, Inc.
Linde Process Plants, Inc.
M&H Enterprises, Inc.
MEI LLC
Nalco Chemical Co.
Ortloff Engineers, Ltd.
Pennwell Corp.
Q.B. Johnson Manufacturing, Inc.

Salof Refrigeration Co., Inc.
Simms Machinery International
Toyo Engineering Corp.
URS
Zeochem

TECHNOLOGY - NITROGEN REJECTION

Air Products and Chemicals
AMCS Corporation
Bechtel
CB&I
Chart Energy & Chemicals, Inc.
Elliott Group
Gas Corporation of America
Guild Associates, Inc.
Gulsby Engineering Inc.
GWD
International Oil & Gas Consultants Pte, Ltd.
J. H. Foglietta Consulting LLC
Linde Process Plants, Inc.
Ortloff Engineers, Ltd.
Pennwell Corp.
Salof Refrigeration Co., Inc.
Thomas Russell Co.
Toyo Engineering Corp.
URS
Vanson Engineering Co.
Zeochem

TECHNOLOGY - OFFGAS RECOVERY

Air Products and Chemicals
AMCS Corporation
Analytical Instruments Corporation
Anguil Environmental
Catalytic Products International, Inc.
CB&I
Dickson Process Systems Ltd.
Elliott Group
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Process Systems SDN BHD
Gly-Tech Services
Guild Associates, Inc.
Gulsby Engineering Inc.
GWD
International Oil & Gas Consultants Pte, Ltd.
J. H. Foglietta Consulting LLC
JGC Corp.
Linde Process Plants, Inc.
Ortloff Engineers, Ltd.
Pennwell Corp.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
Simms Machinery International
Specialty Process Equipment Corporation
Toyo Engineering Corp.
URS
Valerus
Zeochem

TRAINING, PUBLICATIONS - PIPELINE MAPS & DATA

BENTEK Energy LLC
G2 Partners, LLC
John M. Campbell & Company
Pennwell Corp.
Willbros Group

TRAINING, PUBLICATIONS - PROCESS

Air Products and Chemicals
CB&I
CEI Engineering Associates
Detechtion Technologies
Dickson Process Systems Ltd.
ESD Simulation Training, Inc.
eSimulation Inc.
FairFax Operations, LLC
Federal Services LLC
Gly-Tech Services
Gulf Publishing Company
J. H. Foglietta Consulting LLC
John M. Campbell & Company
Optimized Gas Treating, Inc.
Pennwell Corp.
QuantityWare GmbH
River City Engineering

TREATING - GAS

Air Products and Chemicals
Allied Equipment
Anguil Environmental
Bartlett Equipment Co.
Calgon Carbon Corporation
Catalytic Products International, Inc.
CB&I
Credence Gas Services LLC
Croft Production Systems, Inc.
DBR Technology Center, Div. Schlumberger
Dickson Process Systems Ltd.
Evonik Corporation
EXTERRAN
Gas Corporation of America
Gas Technology Corporation
GEA Refrigeration North America Inc.
Geolex, Inc.
Global Process Systems SDN BHD
Gregory Gas Services, LLC
Guild Associates, Inc.
Gulf Coast Chemical, LLC
Gulsby Engineering Inc.

GWD
Industrial Distributors, Inc.
INEOS Oxide
International Oil & Gas Consultants Pte, Ltd.
John M. Campbell & Company
Johnson Matthey Catalysts
Joule Processing LLC.
Linde Process Plants, Inc.
M Chemical Co.
MEI LLC
Nalco Chemical Co.
Optimized Process Designs
Q.B. Johnson Manufacturing, Inc.
Q2 Technologies, LLC
SAIC Energy, Environment, and Infrastructure
Salof Refrigeration Co., Inc.
Samuel Engineering Inc.
SCFM Compression Systems, Inc.
Select Engineering, Inc.
Sepra-Chem Corporation
SNC-Lavalin E&C
Specialty Process Equipment Corporation
Thomas Russell Co.
Tomcej Engineering Inc.
Troy Construction Co.
Univar USA Inc.
URS
Valerus
Vanson Engineering Co.
Vapor Point, LLC
Welker, Inc.
Zeochem

TREATING - LIQUID

Air Products and Chemicals
Allied Equipment
Anguil Environmental
Calgon Carbon Corporation
Catalytic Products International, Inc.
CB&I
Evonik Corporation
EXTERRAN
Gas Corporation of America
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Process Systems SDN BHD
Gly-Tech Services
Gregory Gas Services, LLC
Gulf Coast Chemical, LLC
Gulsby Engineering Inc.
GWD
Industrial Distributors, Inc.
INEOS Oxide
John M. Campbell & Company
Johnson Matthey Catalysts
Joule Processing LLC.
Linde Process Plants, Inc.
M Chemical Co.
Nalco Chemical Co.
Optimized Process Designs
Pentair Porous Media Corp.
Q2 Technologies, LLC
SAIC Energy, Environment, and Infrastructure
Samuel Engineering Inc.
Select Engineering, Inc.
Sepra-Chem Corporation
SNC-Lavalin E&C
Specialty Process Equipment Corporation
Thomas Russell Co.
Tomcej Engineering Inc.
Troy Construction Co.
Univar USA Inc.
URS
Valerus
Vanson Engineering Co.
Welker, Inc.
Zeochem

Classification of Members

Supplies

Gas Processors Suppliers Association

6526 East 60th Street
Tulsa, Oklahoma 74145
Phone: 918-493-3872
Fax: 918-493-3875
Email: gpsa@GPAglobal.org
http://gpsa.GPAglobal.org

The following is a listing of GPSA member companies classified by the type of services that they provide to the industry.

ADSORBENTS, CATALYSTS, MOLESIEVES

Analytical Instruments Corporation
Anguil Environmental
Calgon Carbon Corporation
Catalytic Combustion Corporation
Catalytic Products International, Inc.
CB&I
CECA Molecular Sieves
Chemical Products Industries, Inc.
Croft Production Systems, Inc.
Evonik Corporation
EXTERRAN
Gly-Tech Services
GRACE Davison
Gregory Gas Services, LLC
Guild Associates, Inc.
Gulf Coast Chemical, LLC
Industrial Distributors, Inc.
Johnson Matthey Catalysts
M Chemical Co.
MIRATECH Corp.
Mueller Environmental Designs
Onsite Power Inc.
Q.B. Johnson Manufacturing, Inc.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
Van Gas Technologies
Western Filter Co., Inc.
Zeochem

ANALYZERS, SAMPLING SYSTEMS

Analytical Instruments Corporation
Analytical Systems International
Bechtel
Cameron Valves and Measurement
Croft Automation LLC
ENGlobal Corporation
FESCO, Ltd
Gly-Tech Services
Heath Consultants Inc.
Intertek
Michell Instruments Inc.
MIRATECH Corp.
Nalco Chemical Co.
Nextteq LLC
Sagebrush Pipeline Equipment
SpectraSensors Inc.
SPL Inc.
Thurmond-McGlothlin, Inc.
Welker, Inc.

AUTOMATION, INSTRUMENTS, PROCESS CONTROLS

Aeon PEC
Analytical Instruments Corporation
Analytical Systems International
Barry D. Payne & Associates, Inc.
Bartlett Equipment Co.
Bechtel
Buffalo Gap Instrumentation & Electrical
Catalytic Combustion Corporation
Catalytic Products International, Inc.
Cimation
Clary E&I Services, LLC
Coastal Flow Measurement, Inc.
Croft Automation LLC
Detector Electronics Corp.
Diablo Analytical Inc.
Elliott Group
EMD, Inc.
F.W. Murphy
Federal Services LLC
Genesis Systems

Global Process Systems SDN BHD
Gregory Gas Services, LLC
HPF Consultants, Inc.
Invensys-Foxboro
KW International
LCM Industries, Inc.
Lockwood International
Michell Instruments Inc.
Mid-States Supply
MIRATECH Corp.
Moore Control Systems Inc.
Nalco Chemical Co.
Nicholas Consulting Group Inc.
Norriseal
Prime Controls, LP
Puffer Sweiven
Rexel Inc.
Salof Refrigeration Co., Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
SPL Inc.
Texas Turbine, Inc.
Thurmond-McGlothlin, Inc.
Vinson Process Controls
Wilson-Mohr

BUILDINGS

Bechtel
Brahma Group Inc.
Croft Automation LLC
Elkhorn Holdings Inc
ENGlobal Corporation
Modern Project Services
Sunland Construction Inc.
Thurmond-McGlothlin, Inc.
United Steel Structures, Inc.

CHEMICALS

Air Products and Chemicals
Airgas, Inc.
Bechtel
Chemical Products Industries, Inc.
Coastal Chemical Co. LLC
Evonik Corporation
Gly-Tech Services
Gregory Gas Services, LLC
Gulf Coast Chemical, LLC
INEOS Oxide
M Chemical Co.
Nalco Chemical Co.
Q2 Technologies, LLC
Solutia - Therminol Heat Transfer Fluids
Univar USA Inc.
Van Gas Technologies

COMPLIANCE (CONTINGENCY PLANS, EMISSION CONTROLS, SAFETY EQUIPMENT)

Anguil Environmental
Applied Consultants, Inc.
Calgon Carbon Corporation
Catalytic Combustion Corporation
Catalytic Products International, Inc.
Croft Production Systems, Inc.
F.W. Murphy
Gly-Tech Services
Heath Consultants Inc.
HJ Baker, PE
MIRATECH Corp.
Nextteq LLC
Onsite Power Inc.
Peerless Mfg. Co.
Robert R. Reis, Attorney-Mediator, P.C.
Vapor Point, LLC
Western Filter Co., Inc.

COMPRESSORS (AND PARTS)

A G Equipment Company
Ariel Corporation
Atlas Copco Gas and Process
Bechtel
Cameron Compression Systems
Cameron Valves and Measurement
Elliott Group
Fabreeka International
FES-Southwest, Inc.
Gas Equipment Company, Inc.
GEA Refrigeration North America Inc.
Global Compressor, LP
Global Process Systems SDN BHD
Guild Associates, Inc.
International Oil & Gas Consultants Pte, Ltd.
J-W Power Company
L.A. Turbine
MidCon Compression LLC
Network International
Neuman & Esser USA, Inc.
Nicholas Consulting Group Inc.
Rino - K&K Compression, Ltd.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Simms Machinery International
Specialty Process Equipment Corporation
Sundyne LLC
Texas Turbine, Inc.
The PROS Company
Valerus
Vanco Equipment Co.
Wellsite Compressor & Equipment Co.
Western Filter Co., Inc.
York Process Systems

Electric Motors (and Supplies)
Bechtel
Buffalo Gap Instrumentation & Electrical
Clary E&I Services, LLC
EMD, Inc.
Gas Equipment Company, Inc.
Mueller Environmental Designs
Network International
Rexel Inc.
Rino - K&K Compression, Ltd.
Rotor-Tech Inc.
Salof Refrigeration Co., Inc.
SEC Energy Products & Services L.P.
Wellsite Compressor & Equipment Co.

ENGINES (AND PARTS)

Air Products and Chemicals
Cameron Compression Systems
Croft Automation LLC
Cummins Inc.
Global Compressor, LP
IPD
J-W Power Company
Mueller Environmental Designs
Network International
Rino - K&K Compression, Ltd.
Valerus
Wagner Power Systems
Wellsite Compressor & Equipment Co.
Western Filter Co., Inc.

FILTERS

Aeon PEC
Bartlett Equipment Co.
Bechtel
Calgon Carbon Corporation
Coastal Chemical Co. LLC
Croft Automation LLC
Fabwell Corporation
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Compressor, LP
Gly-Tech Services
Gregory Gas Services, LLC
Industrial Distributors, Inc.
Johnson Screens
Jonell, Inc
J-W Power Company
KW International
MIRATECH Corp.
Modern Project Services
Mueller Environmental Designs
PECOFacet
Pentair Porous Media Corp.
Q.B. Johnson Manufacturing, Inc.
Rotor-Tech Inc.
Royal Filter Mfg. Co., Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Sepra-Chem Corporation
Van Gas Technologies
Welker, Inc.
Western Filter Co., Inc.

FIRED EQUIP (BOILERS, FLARES, HEATERS)

Aeon PEC
Bartlett Equipment Co.
Bechtel
Catalytic Combustion Corporation
Catalytic Products International, Inc.
Croft Automation LLC
Croft Production Systems, Inc.
Gas Technology Corporation
Gly-Tech Services
Gregory Gas Services, LLC
International Oil & Gas Consultants Pte, Ltd.
KW International
Modern Project Services
Moore Control Systems Inc.
Optimized Process Furnaces
Q.B. Johnson Manufacturing, Inc.
TriTex Technologies Inc.

INDUSTRIAL AND SPECIALTY GASES

Accurate Gas Products L.L.C.
Air Products and Chemicals
Airgas, Inc.
Analytical Instruments Corporation
Gas and Supply
Superior Specialty Gas Services, Inc.

MEMBRANES

Air Products and Chemicals
Evonik Corporation
Guild Associates, Inc.
Industrial Distributors, Inc.

ODORIZATION, ODOR CONTROL

Anguil Environmental
Calgon Carbon Corporation
Catalytic Combustion Corporation
Catalytic Products International, Inc.
Heath Consultants Inc.
M Chemical Co.
Mueller Environmental Designs
Nalco Chemical Co.
Peerless Mfg. Co.
Sagebrush Pipeline Equipment
Vapor Point, LLC
Welker, Inc.

PACKAGED SYSTEMS

A G Equipment Company
Aeon PEC
Air Products and Chemicals
Allied Equipment
Analytical Instruments Corporation
Bechtel
Catalytic Combustion Corporation
Catalytic Products International, Inc.
Credence Gas Services LLC
Croft Production Systems, Inc.
Detector Electronics Corp.
Dickson Process Systems Ltd.
EPC Inc.
EXTERRAN
Federal Services LLC
FES-Southwest, Inc.
Gas Technology Corporation
GEA Refrigeration North America Inc.
Global Process Systems SDN BHD
Gly-Tech Services
Guild Associates, Inc.
Hunt, Guillot & Associates
Joule Processing LLC.
J-W Power Company
Koch-Glitsch, LP
KW International
Linde Process Plants, Inc.
Louisiana Valve Source, Inc.
MODEC International Inc.
Network International
Nicholas Consulting Group Inc.
Peerless Mfg. Co.
Pentair Porous Media Corp.
Q.B. Johnson Manufacturing, Inc.
Regard Resources Co., Inc
Sagebrush Pipeline Equipment
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
Specialty Process Equipment Corporation
SPL Inc.
Texas Turbine, Inc.
Thurmond-McGlothlin, Inc.
Valerus
Wagner Power Systems
Welker, Inc.
Wellsite Compressor & Equipment Co.
Whitlow Professional Services
Wilson-Mohr
York Process Systems

PIPE, VALVES, FITTINGS, REGULATORS

Accurate Gas Products L.L.C.
Aeon PEC
Airgas, Inc.
American Steel Pipe
Analytical Instruments Corporation
ARC Energy Equipment
Bartlett Equipment Co.
Bechtel
Cameron Valves and Measurement
Chromatic Industries
Corpac Steel Products Corp.
Croft Automation LLC
F.W. Murphy
Federal Services LLC
FESCO, Ltd
Fisher Controls
Future Pipe Industries
Gas Equipment Company, Inc.
Gas Technology Corporation
Genesis Systems
Gly-Tech Services
Gregory Gas Services, LLC
Joule Processing LLC.
J-W Power Company
Kimray Inc.
KW International
LCM Industries, Inc.
Lockwood International
Louisiana Valve Source, Inc.
Mid-States Supply
Modern Project Services
Network International
Norriseal
Sagebrush Pipeline Equipment
Salof Refrigeration Co., Inc.
Scott Measurement Service Inc
SPL Inc.
Superior Specialty Gas Services, Inc.
Thurmond-McGlothlin, Inc.
Vinson Process Controls
Welker, Inc.

PIPELINE EQUIPMENT (INSTALLATION, PIGGING, REPAIR)

Air Products and Chemicals
Bechtel
Brahma Group Inc.
Coastal Chemical Co. LLC
Croft Automation LLC
Fabreeka International
Future Pipe Industries
Sagebrush Pipeline Equipment
Select Engineering, Inc.
Specialty Process Equipment Corporation
Sunland Construction Inc.
Thurmond-McGlothlin, Inc.
Wagner Power Systems
Western Filter Co., Inc.

PROCESS EQUIPMENT - AIR COOLERS

Aeon PEC
Bartlett Equipment Co.

Bechtel
Chart Energy & Chemicals, Inc.
Credence Gas Services LLC
Croft Production Systems, Inc.
EXTERRAN
Gas Technology Corporation
GEA Refrigeration North America Inc.
Gly-Tech Services
Gregory Gas Services, LLC
Hammco Inc.
Jord International
Joule Processing LLC.
J-W Power Company
Kimray Inc.
Network International
Niagara Blower Heat Transfer Solutions
Onsite Power Inc.
Ref-Chem, L.P.
Salof Refrigeration Co., Inc.
Smithco Engineering, Inc.
Toyo Engineering Corp.

PROCESS EQUIPMENT - DEHYDRATION

Aeon PEC
Air Products and Chemicals
Allied Equipment
ARC Energy Equipment
Bechtel
Croft Automation LLC
Croft Production Systems, Inc.
Dickson Process Systems Ltd.
EXTERRAN
Fabwell Corporation
Gas Corporation of America
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
Gly-Tech Services
Gregory Gas Services, LLC
Guild Associates, Inc.
Gulsby Engineering Inc.
International Oil & Gas Consultants Pte, Ltd.
J.W. Williams Inc.,a Flint Energy Services Co.
Johnson Screens
Joule Processing LLC.
J-W Power Company
Kimray Inc.
Koch-Glitsch, LP
KW International
Linde Process Plants, Inc.
Louisiana Valve Source, Inc.
Michell Instruments Inc.
Network International
Nicholas Consulting Group Inc.
Norwood S&S, LLC
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Regard Resources Co., Inc
Rhine Ruhr Pty Ltd
Rotor-Tech Inc.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
Specialty Process Equipment Corporation
Thomas Russell Co.
Toyo Engineering Corp.
Valerus
Van Gas Technologies
Welker, Inc.

PROCESS EQUIPMENT - MEASUREMENT

Analytical Instruments Corporation
Bechtel
Cameron Valves and Measurement
Chromatic Industries
Croft Automation LLC
EMD, Inc.
Federal Services LLC
FESCO, Ltd
Fluenta Inc.
GEA Refrigeration North America Inc.
Gly-Tech Services
Heath Consultants Inc.
J.W. Williams Inc.,a Flint Energy Services Co.
J-W Power Company
Kimray Inc.
L.A. Turbine
Louisiana Valve Source, Inc.
Nextteq LLC
Omni Flow Computers, Inc.
Sagebrush Pipeline Equipment
Select Engineering, Inc.
Southern Flow Companies, Inc.
Specialty Process Equipment Corporation
SPL Inc.
Superior Specialty Gas Services, Inc.
Thurmond-McGlothlin, Inc.
Toyo Engineering Corp.
Welker, Inc.
Wilson-Mohr

PROCESS EQUIPMENT - TURBOEXPANDERS

Air Products and Chemicals
Atlas Copco Gas and Process
Bartlett Equipment Co.
Bechtel
Genesis Systems
International Oil & Gas Consultants Pte, Ltd.
Joule Processing LLC.
L.A. Turbine
Salof Refrigeration Co., Inc.
Simms Machinery International
Specialty Process Equipment Corporation

Texas Turbine, Inc.
Thomas Russell Co.
Toyo Engineering Corp.

PROCESS EQUIPMENT - VAPOR RECOVERY UNITS

Air Products and Chemicals
Analytical Instruments Corporation
Bechtel
Catalytic Combustion Corporation
Dew Point Control LLC
EPC Inc.
EXTERRAN
Fabwell Corporation
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
Gly-Tech Services
Gregory Gas Services, LLC
Guild Associates, Inc.
J.W. Williams Inc.,a Flint Energy Services Co.
Joule Processing LLC.
J-W Power Company
Kimray Inc.
KW International
Louisiana Valve Source, Inc.
Network International
Norwood S&S, LLC
Ref-Chem, L.P.
Salof Refrigeration Co., Inc.
Select Engineering, Inc.
Texas Turbine, Inc.
Toyo Engineering Corp.
Valerus
Vapor Point, LLC
Welker, Inc.
Wellsite Compressor & Equipment Co.

PROCESS EQUIPMENT - VESSELS, TANKS

Aeon PEC
ARC Energy Equipment
Bechtel
Credence Gas Services LLC
Croft Production Systems, Inc.
Dew Point Control LLC
Dickson Process Systems Ltd.
Eaton Metal Products Company
Fabwell Corporation
Fagen Inc.
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
Gly-Tech Services
Gregory Gas Services, LLC
HETSCO, Inc.
Industrial Distributors, Inc.
International Oil & Gas Consultants Pte, Ltd.
J.W. Williams Inc.,a Flint Energy Services Co.
Johnson Screens
Jord International
Joule Processing LLC.
Kimray Inc.
Koch-Glitsch, LP
KW International
Louisiana Valve Source, Inc.
Mueller Environmental Designs
Network International
Nicholas Consulting Group Inc.
Norwood S&S, LLC
Paragon Field Services
PECOFacet
Peerless Mfg. Co.
Pentair Porous Media Corp.
Q.B. Johnson Manufacturing, Inc.
Regard Resources Co., Inc
Rhine Ruhr Pty Ltd
Rino - K&K Compression, Ltd.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
SEC Energy Products & Services L.P.
Select Engineering, Inc.
Specialty Process Equipment Corporation
Toyo Engineering Corp.
Trinity Containers, LLC
Valerus
Welker, Inc.
Western Filter Co., Inc.

PROCESS EQUIPMENT - WASTE HEAT RECOVERY

Aeon PEC
Anguil Environmental
Atlas Copco Gas and Process
Bartlett Equipment Co.
Bechtel
Catalytic Products International, Inc.
EXTERRAN
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Gly-Tech Services
International Oil & Gas Consultants Pte, Ltd.
Joule Processing LLC.
Nalco Chemical Co.
Network International
Nicholas Consulting Group Inc.
Optimized Process Furnaces
Salof Refrigeration Co., Inc.
Texas Turbine, Inc.
Toyo Engineering Corp.

Process Equipment - Cryogenic
Air Products and Chemicals
Allied Equipment
ARC Energy Equipment
Atlas Copco Gas and Process

Bechtel
Chart Energy & Chemicals, Inc.
Credence Gas Services LLC
EPC Inc.
EXTERRAN
Fabwell Corporation
Gas Corporation of America
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
HETSCO, Inc.
International Oil & Gas Consultants Pte, Ltd.
Joule Processing LLC.
Koch-Glitsch, LP
L.A. Turbine
Linde Process Plants, Inc.
Norwood S&S, LLC
Q.B. Johnson Manufacturing, Inc.
Salof Refrigeration Co., Inc.
SCFM Compression Systems, Inc.
Select Engineering, Inc.
Simms Machinery International
Texas Turbine, Inc.
Thomas Russell Co.
Valerus

PROCESS EQUIPMENT - EXCHANGERS

Aeon PEC
Air Products and Chemicals
ARC Energy Equipment
Atlas Copco Gas and Process
AXH Air-Coolers
Bartlett Equipment Co.
Bechtel
Catalytic Products International, Inc.
Chart Energy & Chemicals, Inc.
Credence Gas Services LLC
Dew Point Control LLC
EXTERRAN
Federal Services LLC
FES-Southwest, Inc.
Gas Technology Corporation
GEA Refrigeration North America Inc.
Genesis Systems
Gly-Tech Services
Gregory Gas Services, LLC
HETSCO, Inc.
International Oil & Gas Consultants Pte, Ltd.
J.W. Williams Inc.,a Flint Energy Services Co.
Joule Processing LLC.
L.A. Turbine
Masters Process Equipment
Network International
Nicholas Consulting Group Inc.
Peerless Mfg. Co.
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Regard Resources Co., Inc
Salof Refrigeration Co., Inc.
Specialty Process Equipment Corporation
Toyo Engineering Corp.
York Process Systems

PROCESS EQUIPMENT - LNG

Air Products and Chemicals
ARC Energy Equipment
Atlas Copco Gas and Process
Bechtel
Credence Gas Services LLC
Elliott Group
EXTERRAN
Fabwell Corporation
Gas Corporation of America
GEA Refrigeration North America Inc.
Genesis Systems
Global Process Systems SDN BHD
Guild Associates, Inc.
International Oil & Gas Consultants Pte, Ltd.
Johnson Screens
Koch-Glitsch, LP
KW International
L.A. Turbine
Linde Process Plants, Inc.
MEI LLC
Norwood S&S, LLC
Q.B. Johnson Manufacturing, Inc.
Ref-Chem, L.P.
Salof Refrigeration Co., Inc.
Simms Machinery International
Specialty Process Equipment Corporation
Texas Turbine, Inc.
Toyo Engineering Corp.

PUMPS

Atlas Copco Gas and Process
Bartlett Equipment Co.
Bechtel
Best PumpWorks
Federal Services LLC
Gas Equipment Company, Inc.
Gas Technology Corporation
Gly-Tech Services
Gregory Gas Services, LLC
International Oil & Gas Consultants Pte, Ltd.
Joule Processing LLC.
Kimray Inc.
Network International
Puffer Sweiven
Rotor-Tech Inc.
Select Engineering, Inc.
SERO Pump Systems, Inc.
Sundyne LLC
Valerus
Vanco Equipment Co.

Wagner Power Systems
Welker, Inc.
Western Filter Co., Inc.

RECONDITIONED, SURPLUS EQUIPMENT

Aeon PEC
Air Products and Chemicals
Analytical Instruments Corporation
ARC Energy Equipment
Best PumpWorks
Cameron Valves and Measurement
Croft Automation LLC
Croft Production Systems, Inc.
Gas Corporation of America
Gas Technology Corporation
Global Process Systems SDN BHD
Gly-Tech Services
Gregory Gas Services, LLC
HPF Consultants, Inc.
Joule Processing LLC.
KW International
Louisiana Valve Source, Inc.
Network International
Regard Resources Co., Inc
Rino - K&K Compression, Ltd.
SEC Energy Products & Services L.P.
Simms Machinery International
Thurmond-McGlothlin, Inc.
Vinson Process Controls
Wellsite Compressor & Equipment Co.

SOFTWARE

Atlas Copco Gas and Process
Chemstations, Inc
Cimation
Detechtion Technologies
EMD, Inc.
ENGlobal Corporation
Joule Processing LLC.
Quorum Business Solutions, Inc.
Spectrum-Prime Solutions, L.P.

NOTES: