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ARE WE REACHING A MATURE AGE IN GAS TECHNOLOGY?

Is there any technology step missing that could add value to the production chain? Do we need to return to our roots to re-engineer? Which are the emerging technologies?

Through the review of the gas processing building blocks, we discover some of the emerging technologies. However, the key issue resides in understanding what the drivers are that will make these technologies acceptable and how they adapt to the global scenario. Most of today's gas processing technology is the result of years of experience in an extremely competitive market, as is the US. How would this apply in a worldwide context? How would emerging technologies be justified on a global basis? What is the impact of information technology?

INTRODUCTION

We are entering into an economic cycle where natural gas is going to play a greater role as an energy source than it played in the past century. It has been called the *Gas Economy* [1]. This paper is not intended to discuss this new cycle, but to review the gas processing technological trends and their potential to play a leading role in this new *Gas Economy*.

THE LAST FIFTY YEARS

Fifty years ago, the development of refrigerated absorption oil plants provided the ability to recover ethane that was "incidentally" absorbed. The market for ethane increased as the market for plastics increased. A "products" pipeline system was developed in the United States to bring demethanized NGL to central fractionation plants where ethane could be separated and transported by pipeline to ethylene production plants (*See Fig. 1)*. Ethane delivered in this manner supplemented and supplanted propane being cracked to produce ethylene. In Europe, the gas business was predominantly a utility business and had very little application to the production of derivatives from natural gas, where petrochemicals are derived from oil cuts. [2]

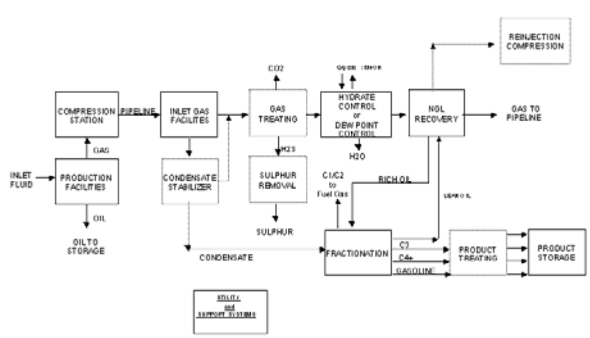


Figure 1 – Gas Processing Block Diagram Absorption Technology, No Ethane Recovery Mid 50's

As the markets for plastics and ethane increased faster than the supply of "incidental" ethane, a few refrigerated absorption oil plants were built based on the economics of recovering additional ethane. But the project economics were marginal due to the increased capital and operating costs of these plants. The increase in required oil circulation resulted in large equipment throughout the plant, with resultant increases in utility and other operating costs (*See Fig 2).*

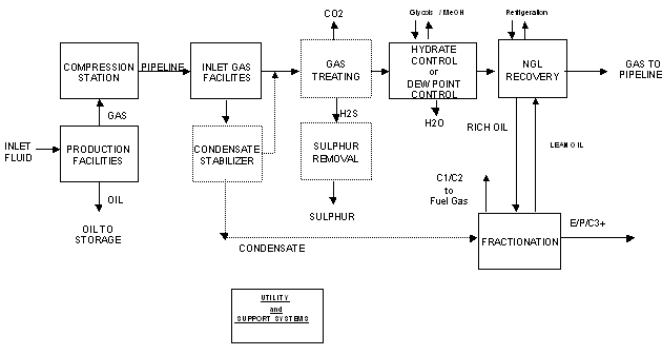


Figure 2 – Gas Processing Block Diagram Refrigerated Absorption, Ethane Recovery 15-50% Mid 60's

In January of 1964, the first turboexpander plant started operations to recover propane-plus from natural gas, based on a "free pressure drop", in an application where inlet gas was being delivered at 600 psig and was required at only 200 psig for fuel purposes [3]. The opinion then was that expanders were applicable "*only when free pressure drop was available*".

What came after is a great chapter of the gas business industry *(See Fig 3)*. The success of this operation led to the concept of recovering ethane by deep refrigeration, economically obtainable by the expander process. Additionally technical studies improved the design sufficiently so that ethane recoveries of about 60 percent could be obtained economically even when the expense of recompression to return processed gas to inlet pressure was required and included. Within two years, the great majority of ethane recovery plants being built were of the turboexpander type.

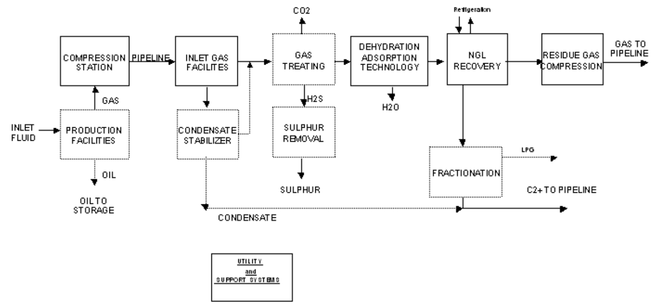


Figure 3 – Gas Processing Block Diagram Turboexpander Technology, Ethane Recovery 80% Mid 70's

Design ethane recovery had increased to the level that 90-plus percent recovery of ethane in the inlet gas had been achieved *(See Fig 4)*. The refrigerated absorption process became obsolete for ethane and propane recovery, essentially due to the process and mechanical simplicity, decreased maintenance, reduced utilities, safety, and reduced labor requirements of the expander process. Conventional refrigerated absorption rarely receives consideration nowadays.

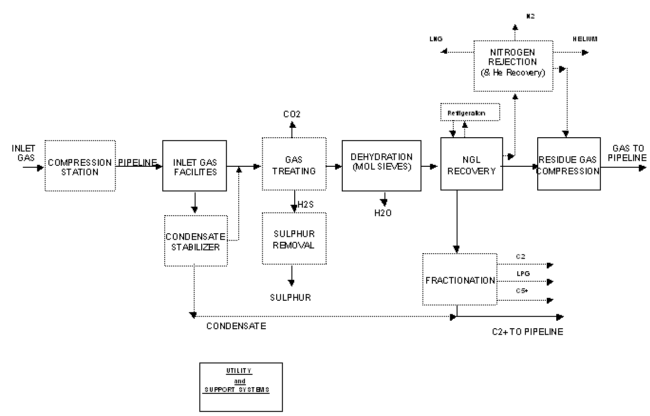


Figure 4 – Gas Processing Block Diagram Turboexpander Technology, Ethane Recovery 90%+ 80s - 90s

Several issues developed as a consequence of the new expander technology:

- Need of deeper water removal

  The industry responded with the development of specialty adsorbents to remove water to levels below one part per million, which became the technology of preference.

- Need of CO_2 removal to control the formation of CO_2 solids in cryogenic sections of the plant (demethanizers).

  The technology available at the time - chemical and physical absorption - was sufficient to capture the need of the new market, as it continues today.

- Development of adequate metallurgy to withstand the process conditions.

- Need to optimize the heat recovery system.

  Several techniques were developed for the use of integrated energy sources. Pinch technologies became a very popular design tool among the process technologists.

- Need to optimize the process design to reduce the energy consumption in residue gas recompression.

  This presented one of the biggest challenges that the turboexpander designers had to overcome because initially, this process was only justifiable on a free pressure drop basis. A new paradigm had emerged. In this sense, the optimization of operating conditions and the continuous challenge of design limitations were instrumental for the consolidation of this technology *(See Fig 5)*.

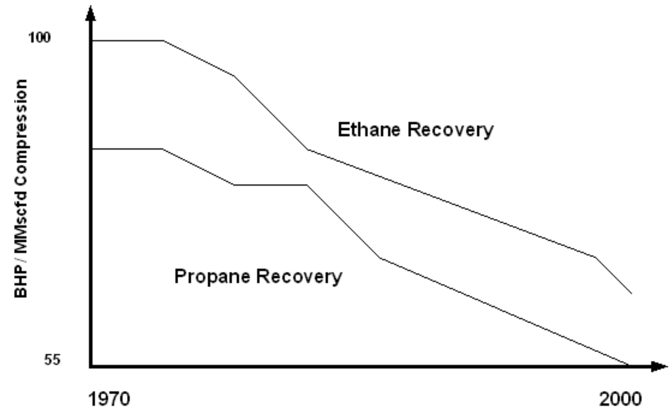


Figure 5 – Compression Requirements for NGL Plants

These challenges created the need to have design tools adequate to accurately predict phase behavior, solids formation and equilibrium. The industry, academia and research centers worked intensively to develop applicable knowledge in these fields. Creative and innovative solutions emerged from this race to gain strategic technology positions. Technologies like CO_2 extractive distillation, the sub-cooled reflux process and the cryogenic acid gas separation are examples of those solutions, some of which became very popular in the market. We can say without mistake that the last 50 years have been enormously fertile from the technical standpoint.

FORECASTS FOR DEMAND OF NATURAL GAS

Twenty five percent of the world primary energy demand is satisfied by gas. Gas production levels will need to be increased in order to meet the anticipated level of growth in the demand. Current sources need to be expanded and new ones have to be developed. The entire infrastructure will have to be adapted for this growth. In North America, only it is expected that the demand of natural gas will expand from 24 tcf in 2000 to 34.2 tcf in 2020. So, looking at these figures, one essentially concludes that more pipeline infrastructure, processing and storage are required.

The new millennium is signaled with increasing demand growth for gas. However the gas industry could get trapped on its own success. At a minimum, there will be huge infrastructure requirements to serve an expanding gas market. The next decade will require the discovery and connection of as much as 300 trillion cubic feet of gas in North America, the development of major new supply frontiers and the infrastructure to meet volatile demand patterns from the growing power sector.

The overall size of the gas business is expected to grow at a pace that exceeds that of the 1990s. This growth will come with much greater risk. Ongoing deregulation of the gas and power industries will expose more businesses and assets to competitive markets. Also, there will be unexpected consequences from the information revolution on the entire industry. The combination of these forces will be a volatile mix that will test the industries' agility and savvy in responding to market pressures while meeting the needs of customers, investors and employees. Those that can adapt will be true industry leaders.

THE EFFECTS OF GLOBAL-IZATION

As more information is rapidly shared in our interconnected world, global considerations change business practices. Our focus is then shifted to achieve equilibrium where we look at competing globally but are still influenced by our local and regional conditions. We need to look at worldwide value creation. How would a technology achieve leadership in the global economy? Is the global economy technology driven or market driven?

Regional idiosyncrasies need to be examined and carefully studied. The fact that a new technology exists doesn't necessarily mean that it will receive immediate acceptance. How and when technology is accepted is determined by its associated safety risks, environmental impact, business differentiation, revenue generation and added value.

We believe that success in the global market economy is sustained by solutions that are site sensitive. What does it take to economically produce the acid gas of Southeast Asia, or sour gas from the Saudi Arabian fields, or the coalbed gas of the San Juan Basin? We cannot export a design that fits the economics of the American market with business premises that are totally different in other regions of the world. A project in offshore West Africa to recover liquids from flared gas doesn't necessarily have to use energy efficient operations, but it does have to offer a balance of product recovery and project economics that satisfies the project stockholders and meets the goal of eliminating gas flaring.

New forces are acting to promote the occurrence of business opportunities in non-traditional areas. In some cases, these business opportunities do not necessarily need to use the state-of-the-art that satisfies the economics of the same type of project in other regions, or those for which that technology was envisioned, but rather those specific to serve the project, its region and economics.

Today natural gas economics is better understood. In the '50s, natural gas was a marginal product, a result of oil production. Today, natural gas is vehicle for growth, progress and economical development.

REVIEW OF THE GAS PROCESSING CHAIN

The diagram below represents a complex chain of gas processing steps with multiple derivations and uses *(See Fig 6).* The production chain could be for producing a gas at conditions to be transported, extracting liquids, upgrading gas value, preparing feed for liquefaction, or producing feedstock for a chemical facility.

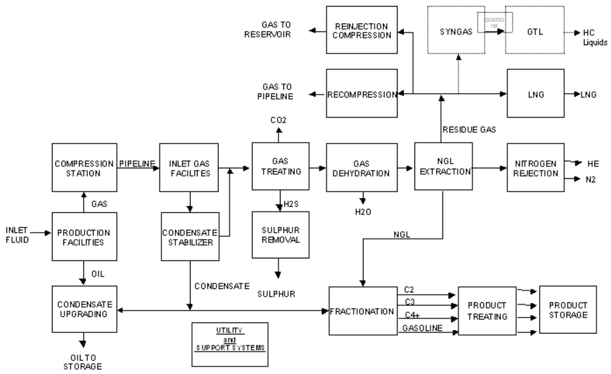


Figure 6 – Gas Processing Block Diagram

Each block represents a unit operation related to phase separation, absorption, adsorption and distillation in combination with fluid transport, heat exchange and energy support systems like refrigeration and heat medium supply. In some cases, there is chemical reaction with minimum use of proprietary catalysts.

A first attempt to answer our initial question causes us to analyze the concept of maturity in this context. We can think of a technology being mature when it has achieved a degree of development in which the breadth of knowledge is fully understood and has not received any improvements or contributions for a period of time.

What follows is a series of variations and optimization cycles that will go on until either commercially or technically, there is no longer incentive to continue.

The turboexpander technology experienced intense development in its first two decades. It achieved the position as the technology-of-choice, overcoming most of the different operating hurdles and lately being further optimized. The development in "proprietary technology" has been focused basically in optimizing the heat exchange network.

We believe that a technology development is more than merely an arrangement of process streams and exchangers. It is digging into the fundamentals and working with the root of the problem. It is exploring a new path, or taking a challenge and crossing through delicate regions. When the economics justify this new path, we can say that we are in the presence of a new technology.

A study conducted in 1995 by the National Petroleum Council revealed that the technologies with most impact to the gas operators were:

- Energy efficient process
- Energy efficient equipment
- Separation technologies
- Acid gas removal and gas dehydration
- Separation of high impurities
- Trace constituents
- Hydrate prevention
- Multiphase pumps
- Compression efficiency

Some operators expressed concern and impatience with the pace of technology development. Others complained that there have been very few technological advances in areas like acid gas treatment and hydrocarbon separation. Acid gas treatment with solvents has not changed essentially for more than 70 years. The latest advancement in hydrocarbon separation was cryogenic separation in the '60s.

The figures below *(See Figs 7 and 8)* depict technology cycles and technology maturity. A quick look indicates that the technologies in use in gas processing are in a state of maturity. The focus of the new developments should concentrate in those technologies located in the middle of the graph.

The analysis of the building blocks and their constitutive elements will give us an understanding of where the technology stands today and what "new paths" are being explored, keeping central safety, environmental friendliness and operability. (For an abbreviated analysis see Summary Table in Appendix I.)

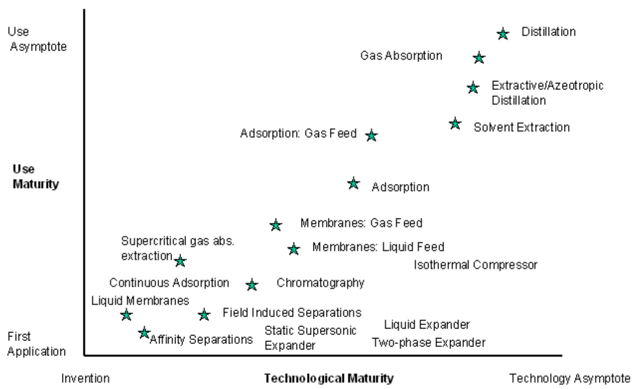


Figure 7 – Established and Emerging Technologies

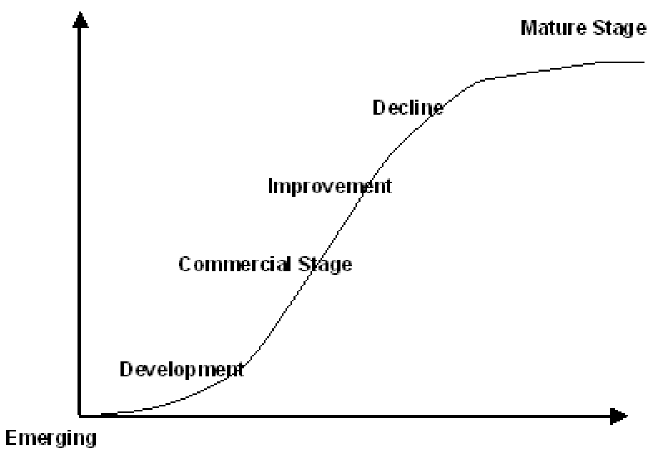


Figure 8 – Technology Cycles

In the analysis that follows, for the sake of simplification, we will not elaborate in detail on the current technologies used, but rather focus on the possible new paths or developments that could be of interest.

Production Facilities

New technologies should focus on providing cost effective gas production while minimizing real estate requirements. Offshore sub-sea offers an opportunity for technology growth, challenging the current offshore surface platform environment to find a solution that is encapsulated in a non-traditional solution and demands high technical focus (*See Fig 9)*.

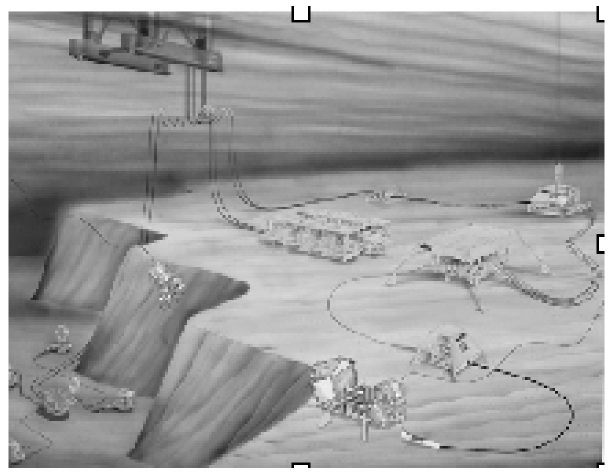


Figure 9 – Production Offshore Sub-Sea Systems

Some technical solutions in the production area are:

A) Development of new production techniques:
- Recycling and reinjection
- Reinjection of hydrocarbons and non-hydrocarbon gases (CO_2 and N_2)
- Use of miscible gas displacement to improve recovery efficiency
- New thermodynamic models to correctly predict the behavior of phases

B) Multiphase pumps that can act as pumps or compressors or both at the same time. Existing multiphase pumps are positive displacement, twin screw type pumps. They are capable of handling continuous gas volumes of over 97% as well as 100% slugging. Potential uses for the multiphase pumps are in offshore fields and pipeline transportation. The manufacturer reports models built for 250,000 bpd.

Because of its reduction in size and the ability of handling two phases, this technology has the potential of becoming a central piece in future developments *(See Fig 10)*.

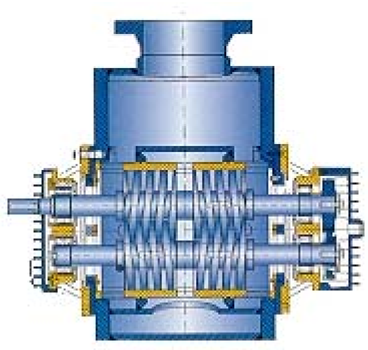


Figure 10 – Production Facilities, Emerging Technology Multiphase Pumps (courtesy of Bornemann Pumps)

C) Three-phase turbine separation technology, which is used to generate power from gas-liquid mixtures, separate the gas from liquids, and separate liquids of different densities *(See Fig. 11)*.

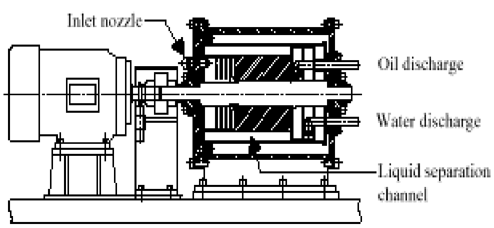


Figure 11 – Rotary Three Phase Separator

The potential applications of this technology are enormous:

- Oil and gas production, to replace offshore and onshore separation equipment and to obtain energy
- Downhole gas-water separation
- Downhole gas-oil-water separation

Pipelines and Compression Stations

A key objective is to reduce the cost of gas transport by 25% over the next five years. The goal is to improve the economic profitability of pipeline gas transport by reducing the pressure loss in gas pipelines and to optimize compression efficiency.

New technologies should impact not only compression efficiencies to reduce gas horsepower requirements, but should impact the whole system efficiency, compressor plus driver, considering the use of efficient cogeneration systems. New technologies should also improve mechanical reliability, equipment operational safety and mechanical integrity.

Other key elements in the optimization of pipeline cost are: improvements of design practices, satellite technology for terrain evaluations, materials, welding procedures, construction and project execution.

A) Pressure loss reduction. Internal coatings, drag reduction agents, advanced surfaces for two types of gas flow: dry gas and gas with condensate. The importance of smooth coatings has been demonstrated in recent projects; they reduce frictional pressure losses and improve internal pipe protection.

B) Improvement of the thermodynamic efficiency of compression equipment. Recent advances are indicating that efficiencies beyond 90% are attainable in compression equipment. The impact that this has is obviously the reduction in horsepower installed for the whole pipeline, or more mileage between compressor stations.

C) <u>Isothermal compression</u>. Isothermal compression can save about 15% of compression cost compared with an adiabatic or polytropic machine. There were several attempts made in the past to develop isothermal compressors and there are actually some units in operation. However, this machine did not receive all the support expected from the market. Perhaps the machining tool technology was not cost-effective and the final cost too expensive. We believe that with today's computerized fluid dynamic (CFD) technology and modern computerized tool machining, that chances are, isothermal compressors could be built cost-effectively.

D) <u>Inline Electric Motor Driven Compressor.</u> This is a relative recent development. A compressor is installed inside the pipeline, driven by an electric motor. It could be an attractive cost reduction solution since it eliminates most of the associated auxiliary equipment, compression station building, etc. It is limited to relatively low heads. It has enormous potential for major developments. It also has the advantage that the impeller could be also used to expand gas rather than compressing it. The pipeline is used to store gas, which is released during high consumption hours, and the inline compressor acts as an expander generating energy. The inline compressor uses magnetic bearings, therefore no oil or seals are required, and since it is driven by electricity, it does not pose a concern to the environment. The compressor was initially sized for flows of 500 MMscfd, with an electric motor of 5.5 MW (*See Fig. 12)*. [4]

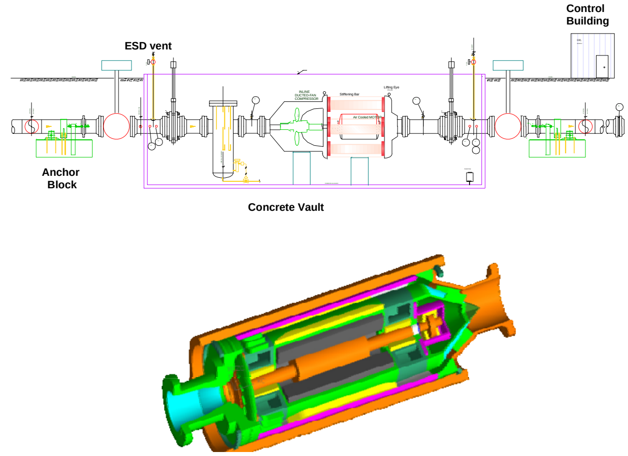


Figure 12 – Inline Electric Motor Driven Compressor (Courtesy of Dresser-Rand)

Inlet Gas Facilities, Stabilization

New technology should focus on achieving cost-effective two-phase separation while reducing space requirements. An inline rotating liquid-vapor could effectively reduce the space requirements and vessel dimensions to separate a two-phase flow. Inlet liquid is separated from the inlet stream and removed from the inlet gas with a bucket-type turbine. This device can work with ample tolerance to liquids volume fluctuations from 0-100% slugs. New technology is being developed in this field and will gain acceptance quite rapidly since the current technology is very expensive and real estate consuming. The impact that this new technology could have for offshore facilities is dramatic *(See Fig. 13).*

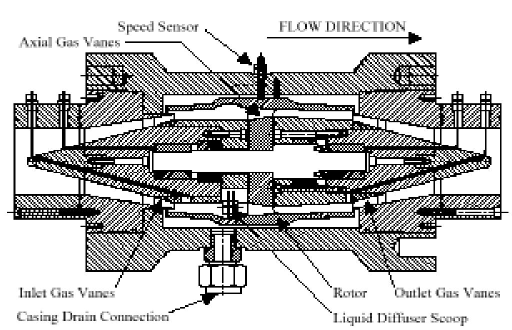


Figure 13 – Pipeline Inline Separator

Gas Treating

New technologies should focus on developing hybrid solutions, capturing the best of diverse technologies and merging them with others to capture synergies. Also important would be the development of faster adsorption mechanisms, allowing more of the gas and adsorbent time-contact.

A) Absorption-Membranes Technology

The combination of diffusion mechanisms associated with chemical or physical solvents could lead to a technology that reduces the size of contacting equipment *(See Fig 14).*

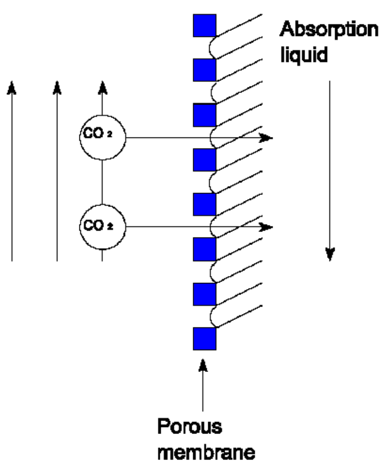


Figure 14 – Hybrid Membrane-Solvent

B) Membranes-Catalysis

Selective catalyst embedded in the fibers of membranes could help in improving the diffusion process to the catalyst.

C) Membranes-Adsorption

Selective catalyst embedded in the fibers of membranes could help in improving the diffusion process trough the adsorbent.

D) Cryogenic Separations

In gases with high carbon dioxide concentrations, it is possible to operate without the need of front-end treatment by strategically altering the vapor-solid equilibrium.

E) Advanced Adsorption - Natural zeolites for cost-efficient natural gas treatment

Adsorption is a surface phenomenon. Applications of adsorption technology will continue to grow in the foreseeable future because the technology has not yet reached its maturity limit.

There is a strong industrial need for low cost processes for the on-site N_2 and CO_2 removal from low BTU natural gas. A highly selective and low cost adsorbent, clinoptilolite natural zeolite, could be applied to develop an innovative adsorption process. The product gas will reach pipeline specifications having a minimum heating value of 960 BTU/SCF and containing at the most mol 4% N_2 and mol 2% CO_2 (maximum allowable). N_2 and CO_2 will be removed in a single reactor. The cost reduction for feed gas having > 10% N_2 is estimated to be around 20% on CAPEX and 30% on OPEX. For a gas with > 10 % CO_2, the cost reduction is estimated to be around 20% on OPEX. In the case of simultaneous N_2 and CO_2 removal, for a natural gas that contains l0% N_2 and 10% CO_2, the cost reduction is estimated to be higher than 50% on both CAPEX and OPEX.

An important element in the development of adsorption technology has been the availability of a very large spectrum of adsorbents with varying pore structures and surface properties, which are responsible for selective adsorption of specific components of a fluid mixture. These include zeolites, activated carbons, aluminas, silica gels, ion exchange resins and polymeric adsorbents.

Another important factor in the development of adsorption technology is the possibility of designing many different process schemes for a given separation need using one or more available adsorbents. Adsorptive processes differ by the modes and conditions of operation of the primary adsorption and desorption steps as well as by numerous other complementary steps that are used to increase the separation efficiency of the process. Some of the key process design goals are to increase the desired product purity and recovery, and to decrease the adsorbent inventory and energy of separation.

The endless choice of adsorbent materials and their use in the design of innovative separation processes provide a very flexible and bright future for this technology as a separation tool.

Continual improvements of the process hardware (adsorber, valves), machinery (compressors, etc.) and control systems used in the adsorptive processes are lowering the cost of separation by adsorption and increasing the scale of its application. Breakthrough technology is moving towards the use of continuous processes rather than step-batch type operations. The future is also bright in this field. It should however, be emphasized that a multidisciplinary integrated research and development effort between material and engineering design is needed to reap the benefits of this fast-changing technology.

F) High Efficiency Gas-Liquid Packing and Contactors for Acid Gas Processing

A DOE-sponsored project is focused on developing more efficient and compact physical solvent systems for upgrading natural gas with high carbon dioxide and/or hydrogen sulfide content. Researchers at the Institute of Gas Technology are working with representatives from the industry to develop and demonstrate the advanced system designs. Advances are required to enable the separation processes to proceed, using structured packing and/or rotating solvent-gas contactors in place of traditional, large absorber towers with many sets of contactor trays. The new designs would allow a five-fold reduction in the size of gas upgrading plants. Such size reduction is particularly valuable for platform scale upgrading in the Gulf of Mexico.

G) Higee ™ technology, studied by GRI, compared with conventional technology has the lowest cost due primarily to the smaller contactor employed. The smaller contactor gives the Higee technology an advantage over the other dehydration technologies evaluated in terms of relative cost contributed to the platform cost and relative total plant investment in combination with relative cost contributed to the platform cost *(See Fig 15)*.

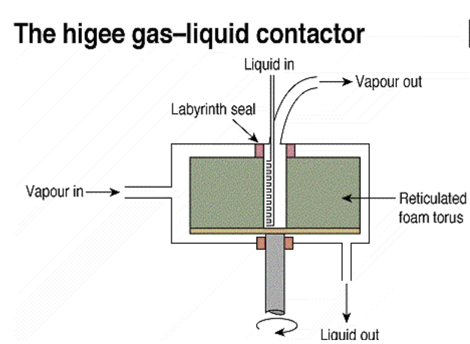


Figure 15 – Separation Technology

H) New non-alkanolamine based solvents, e.g. morpholine, show cost reductions of 30 to 50 percent for impurity concentrations as high as 70 percent carbon dioxide and 3 percent hydrogen sulfide. This new process is accomplished with less hydrocarbon loss and lower cost equipment than previous processes.

I) A paper published by the University of Singapore in 1998 reports the elimination of H_2S by hollow fiber membrane using NaOH as solvent on the permeate-side. Sulfur-containing polymers were tested as membrane materials — polysulfone and polyethersulfone. The polysulfone membrane showed a better H_2S elimination than polyethersulfone. The H_2S concentration in the feed gas was only 16-24 ppm, and the authors stated that this method is suitable for traces of H_2S. The work was a typical small scale lab test.

J) A technology that could inhibit the formation of solid carbon dioxide should be investigated.

K) A new membrane for the removal of mercury *(See Fig 16).*

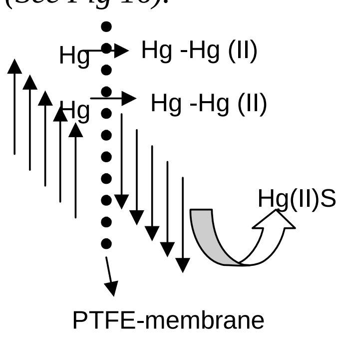


Figure 16 – Membranes for HG from Gas

Sulfur Removal

New technologies should focus on developing alternative options to the Claus process and on innovations in the direct separation of hydrogen and sulfur.

Some recent developments:

A) Dissociating H_2S into its elements is sometimes called H_2S cracking or splitting. Many experimental processes have been devised to make hydrogen from hydrogen sulfide.

$$H_2S \rightarrow H_2 + S$$

The hydrogen in H_2S is quite loosely bound compared to many other simple compounds that contain hydrogen such as water (H_2O) and methane (CH_4). Many researchers around the world have been working on ways to make hydrogen from H_2S *(See Fig 17).*

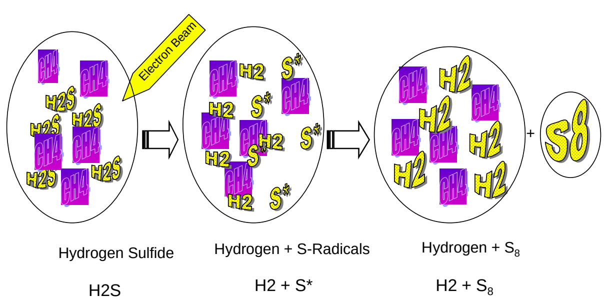


Figure 17 – Selective Splitting of Molecules: H_2S, COS and RSH

Different initiatives are being explored with this alternative, e.g. modified E-beam technology, microwave-plasma.

B) Modified Claus process using fluidized bed reactors *(See Figs 18 and 19)*.

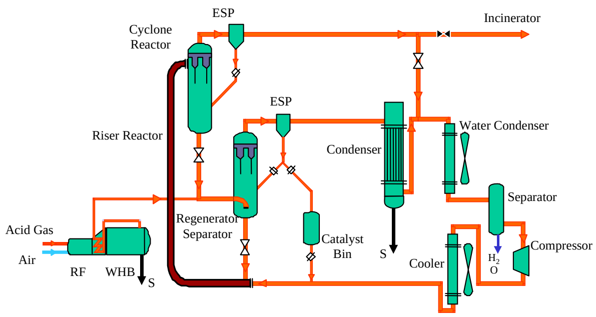


Figure 18 – SSRP Process
(courtesy of SimTech Technologies, Inc.)

Process Advantages

- Unlimited turndown
- Larger catalyst surface area
- Water knock out
- Sub dew-point operation
- No bed switching
- Skid Mount

Process Capabilities

- Large and small plant applications
- Efficiencies to 99.6%
- COS and CS_2 handled
- Lower catalyst requirement
- Normal air demand control
- Fills efficiency gap between SuperClaus™ and SCOT™
- Can be retrofitted as TGCU

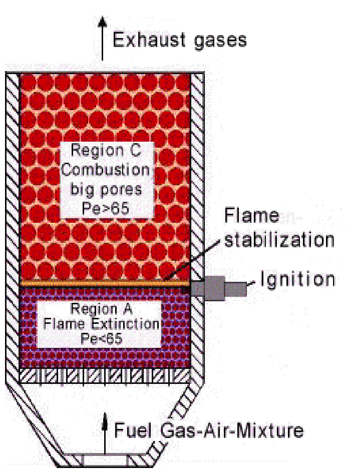
Process Challenges

- Fluidized bed negativity
- Moving parts
- Corrosion / erosion
- Colloidal sulfur
- Dust in tail gas
- Sour water disposal

Figure 19 – SSRP Process
(courtesy of SimTech Technologies, Inc.)

C) Reinjection of H_2S

D) Porous burner *(See Fig 20)*.



A flame propagation only can take place when the Péclet-number criterion is fulfilled:

$$Pe > 65 \qquad [-]$$

The Péclet-number known from the domain of heat transfer is modified in the following way:

$$Pe \equiv \frac{S_L d_m C_p \varrho_f}{\lambda_f} \qquad [-]$$

S_L	[m/s]	laminar flame velocity
d_m	[m]	equivalent pore diameter
C_p	[J/kg K]	specific heat capacity of the gas phase
ϱ_f	[kg/m³]	specific weight of the gas
λ_f	[W/m K]	thermal conductivity of the gas phase

Figure 20 – Porous Medium Burner
(includes previous column)

E) Catalytic porous burner

Gas Dehydration

A) New technology should focus on adsorption as the technology-of-choice to remove water and heavy hydrocarbons. Adsorption has not been exploited to the maximum of its capabilities. A continuous dehydration unit should be considered for large volumes of gas. Fluidized or ebullating bed technologies can be used for this purpose. Vast experience has been acquired in these technologies with their wide use in the oil refining industry *(See Fig 21)*.

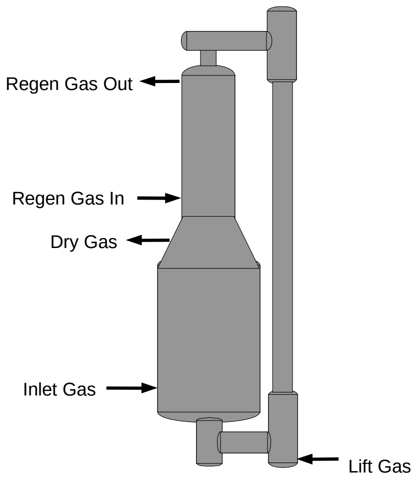


Figure 21 – Continuos Adsorption – Regeneration (an ABB Lummus Global proprietary design)

B) New membrane technology that allows condensable vapors to permeate, such as C_3+ hydrocarbons, aromatics and water vapor, while rejecting non-condensable gases, such as methane, ethane, nitrogen and hydrogen.

C) New frontiers - The University of Santander and ECOPETROL - ICP laboratory (both Columbia) are investigating by means of a water circulation unit the effect of the different intensities of magnetic and electromagnetic fields on the freezing point of water and the freezing times. These results are important for their process development in natural gas treatment e.g. inhibition of the formation of gas hydrates in natural gas. The experience at ECOPETROL - ICP with the application of magnetic fields has been centered on design and installation of tools to avoid the precipitation of paraffins and to improve the process of separation of emulsions.

NGL Extraction

The focus should be on optimizing energy usage in liquids recovery processes, by introducing a new generation of highly efficient expanders. Some important facts to consider:

A) The theoretical requirement to recover 95 percent of ethane from a gas stream is 19 HP/MMscfd, or 10 HP/gpm, based on a medium gas richness composition. Current energy expense to remove liquids from natural gas streams is between 45 to 65 HP/MMscfd, or 20 to 40 HP/gpm.

B) The challenge for technology developers in NGL extraction is to develop high-recovery processes at much lower energy rate, perhaps by exploring a hybrid concept utilizing absorption and turboexpander.

C) The development of high efficiency two-phase expanders and dense phase expanders will allow cryogenic processes to work in different conditions, allowing lower expansion ratios and saving recompression cost *(See Fig 22)*. [5]

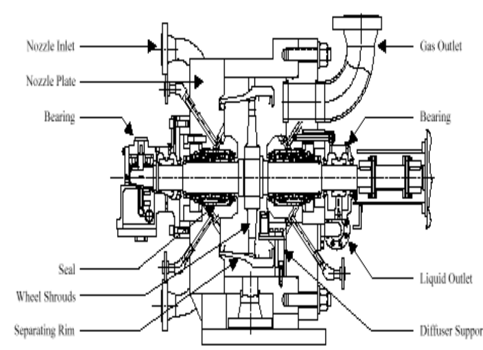


Figure 22 – Two Phase Expander Turbine

D) The development of internal heat-transfer/mass-transfer equipment would help to intensify process equipment and reduce cost *(See Fig 23)*.

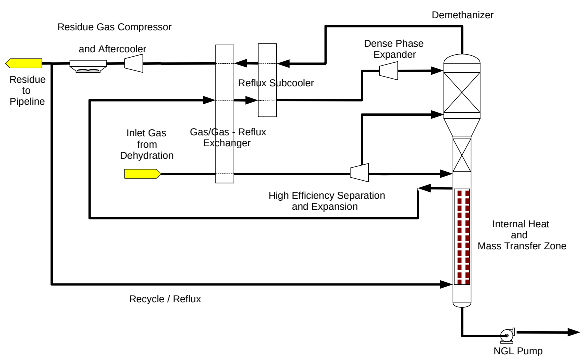


Figure 23 – Advanced Turboexpander Plant (an ABB Lummus Global proprietary technology)

E) Use of emerging membrane technology for gas dew point control.

F) Use of static devices for gas conditioning, liquid separation (Twister technology, Vortex tube)

Fractionation

Fractionation should be analyzed in three parts: the mechanical-hydraulic, mass transfer and distillation column sequencing.

There have been improvements in the mass transfer equipment, new trays and packings. However, design methods are still on the conservative side.

There are new theories in mass transfer and hydrodynamics. These new theories must be understood before developing new design procedures. Today's design methods are still using the first generation of theories based on approaches and correlations. Design procedures must incorporate interphase mass transfer, heat transfer, phase equilibrium and hydrodynamics. Approximated methods of calculations, which were developed before computers were available, perhaps well accepted and useful for quick and approximate estimates, should be replaced by a new generation of design methods.

Distillation column sequencing has received increasing attention in the last 20 years. The distributive distillation concept has demonstrated that it could bring significant cost reductions when the operation is analyzed through the whole life cycle.

In order to achieve world class performance from separation processes, there is a need to improve understanding of, and aim for improvements in, the various phenomena at each scale of observation and occurrence. Starting at the smallest scale, there have been developments in the understanding of molecular diffusion.

Mass transfer is the basis of separations. Fick's law of diffusion still underpins mass transfer design equations. The limitations of Fick's law to describe molecular diffusion is well documented and it has been convincingly argued that the most convenient and general approach to interphase mass transfer is the Maxwell-Stefan approach.

In order to achieve superior performance in separation processes, more attention must be paid to:

A) Improved modeling of interphase mass transfer processes. Fick's law of diffusion is inadequate to handle the problems of today and tomorrow. The Maxwell-Stefan approach to diffusion is recommended for use in place of Fick's law. This approach takes proper account of thermodynamic non-idealities and the influence of external force fields. Furthermore, the Maxwell-Stefan approach can be extended to handle intra-particle diffusion in macro-and porous adsorbents and membranes. The Maxwell-Stefan theory provides some insights into the development of innovative separation processes.

B) Two phase flow on distillation, absorption, and extraction plate and packed columns needs to be better understood. A common approach to gas-liquid and liquid-liquid modeling will lead to improved design procedures and help to reduce scale-up costs.

C) Evaluation of design procedures. Traditionally distillation, absorption and extraction columns have been designed using equilibrium stage approach. Adopting the non-equilibrium or rate approaches as a routine design tool could result in a different method to design this operation.

The correct and general approach to distillation column design is not to use the equilibrium stage but to change, head-on, the complete non-equilibrium problem by taking into account the heat and mass transfer processes on trays. The non-equilibrium stage approach must incorporate the proper Maxwell-Stefan description of interphase mass transfer. Also, simultaneous heat transfer effects need to be incorporated into the model formulation. The incentive to adopt the non-equilibrium stage model approach is that column profile predictions using this approach and the traditional approaches can be markedly different. Such differences could have a significant effect on column design. The major bottleneck in the use of this approach is the lack of generally applicable mass transfer correlations for trays and packings.

D) Separation equipment is far too big and intensification is required.

E) More and more distillation designers need to consider concurrent reactions and find innovative methods to remove product, resulting in improvement of selectivity and better process economics.

F) Process integration of separation systems

Process integration has proven to be very successful in reducing the energy costs for distillation columns. The right sequence should be considered a priority when planning a new facility. Owners-operators are still not fully adopting process-integrated schemes. Capital investment continues to be a deterrent, rather than putting life cycle in perspective.

In the last 30 years, great progress has been achieved in the understanding of how to organize a flowsheet effectively to maximize the energy integration and optimize the use of the sources available.

G) Sequencing of simple distillation columns

The integration of a stand-alone distillation column into a background process is well understood. Not so well understood, however, is the problem of synthesizing a network of distillation columns and its simultaneous heat integration. A sequence of distillation columns is required in cases of homogeneous mixtures with more than two desired product streams.

Procedures for sequencing of simple distillation columns without heat integration are widely available. Many are based on heuristics rules. Another class of synthesis methods is based on thermodynamic criteria. More recently, methods based on mathematical programming have been proposed for the synthesis of distillation sequences. These solution procedures allow heat integration to be considered simultaneously. Methods using artificial intelligence have also been suggested. Recently, a procedure based on the minimization of energy losses in distillation column sequences has been proposed as both analysis and a synthesis tool.

Most of this work has not considered heat integration; however, heat integration may have a significant effect on operating costs. For some time this appeared to be a complex problem requiring simultaneous solution of the sequence together with heat integration.

H) Thermal coupling

Although process integration has proven to be very successful in reducing the energy costs for conventional distillation arrangements, the scope for integrating conventional distillation columns into an overall process is often limited. Also, practical constraints often prevent integration of distillation columns with the rest of the process. If the column cannot be integrated with the rest of the process, or if the potential for integration is limited by the heat flows in the background process, then attention reverts to the distillation operation itself and non-conventional arrangements. Despite the advantages, designers have been reluctant to use thermally coupled systems for the following reasons: lack of established design procedures, fear of control problems, and lack of confidence in applying technology which has not been tested in industrial applications. [6]

I) Co-current gas-liquid contactor

The capacity of conventional column equipment for contacting gases and liquids in processes such as distillation and gas absorption is invariably limited by the maximum allowable gas velocity. This represents the point at which counter-current flow of the two phases can no longer be maintained. A new development is concerned with the gas-liquid contacting stage, which can maintain operation at much higher gas velocities than conventional equipment. This would allow a certain degree of process intensification.

In 1936, Underwood suggested that the capacity of a gas-liquid contactor could be increased by employing contacting stages in which the gas and liquid flow co-currently, while maintaining a counter-current flow pattern over the equipment as a whole. A new gas-liquid contactor has been developed using this concept. A schematic diagram of this contactor is shown in the figure. Each stage consists of an entraining section in which the liquid phase is entrained into the up-flowing gas, and a disentraining section, in which the liquid is separated from the gas, collected and passed to the stage beneath. The illustration shows a column with external pipe work carrying the liquid between stages *(See Fig. 24)*.

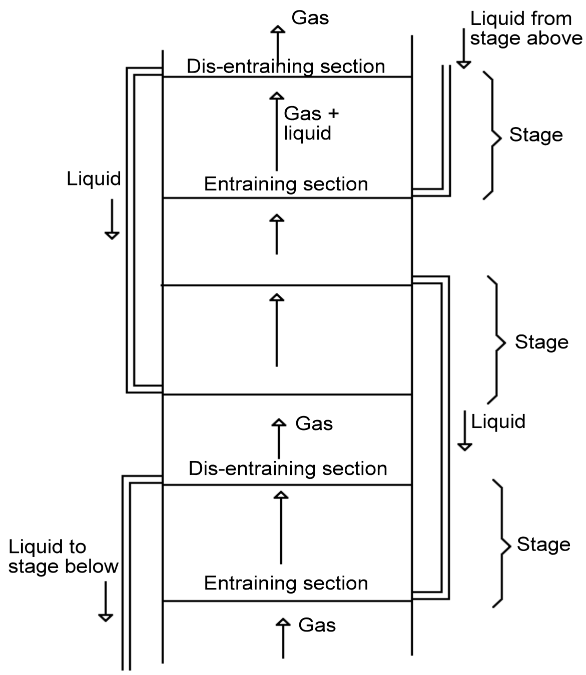


Figure 24 – Distillation

Preliminary results indicate that the new gas-liquid contactor can operate at much higher superficial gas velocities than conventional column equipment.

PRODUCT TREATING

A) Developments in the liquid-liquid mass transfer area will greatly contribute to improve the size of liquid contactors. There are some initiatives underway to use rotating devices to increase the mass transfer.

B) Product scavengers and specialty adsorbents are also seen as a future area of innovation as we see adsorption as an area of growth. Typical applications for adsorption are liquid drying, trace impurity removal and azeotrope separation.

C) Efforts should continue to develop a commercial membrane for liquid treatment. Marathon Oil Co. in Cotton Valley, LA. developed and tested a membrane gas process technology to remove CO_2 at an NGL plant in the mid '90s, with the goal to reduce the CO_2 content from 11.7% to <5 mol %. The unit was installed and run at Marathon's Burns Point gas plant in St Mary Parish, La. Due to the fact that CO_2 and C_2 have similar boiling points, the effective separation is difficult to achieve and the product is contaminated with CO_2.

Marathon Oil Co. applied the treatment by a membrane separation, because the higher CO_2 concentration in the liquid allows membranes to separate more efficiently than in the gas phase. This system was installed in cooperation with Cynara Co. The full-scale unit is able to treat 3000 bpd of NGL carrying 11.7 mol% CO_2,which is reduced to < 5 mol %.

NITROGEN REJECTION

Nitrogen rejection became important during the late '70s and '80s as a viable technology to upgrade low quality gas. On occasion, rich nitrogen gas came associated with helium, which was of national strategic interest. Several technologies are available today to reject nitrogen, mainly using cryogenic separation processes. There are several alternative routes to remove nitrogen that are trying to gain acceptation e.g., pressure swing adsorption, selective solvents and membrane technology.

Like many other treatments, the best selection depends on the case and economics. It is being said that the PSA and membrane options are only good for small volumes. Selective solvents are not economic for volumes bigger than 50 MMscfd, but cryogenic separations are competitive at all ranges. Small units can be robustly designed so they don't need constant attention.

Development continues for a cost-effective membrane technology for nitrogen bulk removal. Equipment intensification concepts should be applied to develop a design for flows higher than 100 MMscfd.

LNG Production

LNG technology has evolved into the use of sophisticated refrigeration systems, with mixed refrigerants and proprietary designed heat exchangers. Development of industrial scale gas turbines has allowed this machinery to enter this market successfully. Today, 5% of world gas demand is transported by LNG (growing from 20 mte/yr in 1980 to 90 mte/yr in 1999).

The LNG market will grow at an intensive pace, in competition with emerging technologies to convert gas into saleable clean fuels. The LNG business will progressively transform from a chain based stream into an open spot market. Floating LNG facilities are more frequently studied as economical solutions to monetize offshore reserves. None have been built or ordered yet, but its appearance is imminent *(See Fig 25)*.

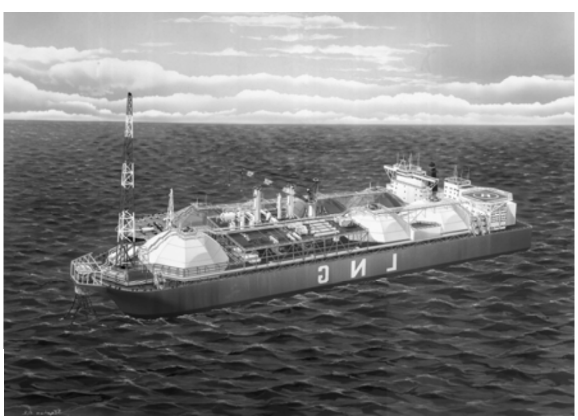


Figure 25 – LNG FPSO
(courtesy Moss Maritime)

A) New LNG opportunities should adopt turboexpander technologies that offer simplicity and eliminate the sophisticated and expensive refrigeration systems. Several new concepts are emerging in this segment and they will soon be competing with the classical technologies, opening the opportunity for significant cost reductions.

B) Thermoacoustic refrigeration, a very new field of technology, can provide innovative technology without moving parts. This technology has been demonstrated on a relatively small scale. Thermal efficiencies in the 80 percent range are expected. A pilot unit is to be completed for the year 2003. Projecting ourselves into an economy with hydrogen, this technology could be instrumental for hydrogen liquefaction. [7]

Gas Hydrates Production

It is assumed that there is about 10 times more CH_4 hydrate on earth than in gas reservoirs. The US, Japan and Germany are leading the gas hydrate geology effort. The exploitation is still unsolved, but solutions will certainly develop and then gas processing is going to be a very big issue *(See Fig 26)*.

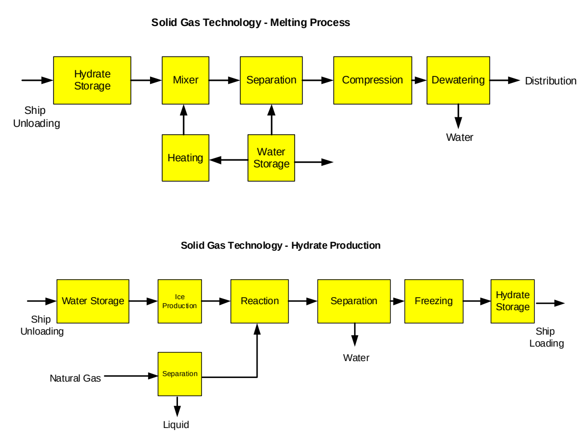


Figure 26 – Hydrates Production Facilities

Theoretically, 180 m^3 of natural gas at standard conditions (1 bar, 15°C) will be released upon melting 1 m^3 of natural gas hydrates. Frozen hydrate can be used to transport large volumes of natural gas over long distances. The frozen hydrate concept is based on the discovery that natural gas hydrate remains stable at atmospheric pressure when stored under near-adiabatic conditions at temperatures below the freezing point of water. A natural gas hydrate (NGH) transport chain comprises hydrate production, marine transport and re-gasification facilities. Studies indicate that the NGH chain has the potential of reducing the delivered cost of natural gas considerably compared to established LNG technology.

Gas-to-Liquids, Chemicals

An essential step in this emerging technology is to reduce the costs of the reforming step and the hydrocarbon synthesis.

Five percent of the world's gas goes to chemicals (especially NH_3 and H_2) and hydrogen. There is a need to focus on the development of a new technology, like methanol-to-olefins. A new petrochemical industry can emerge from this initiative *(See Fig 27).*

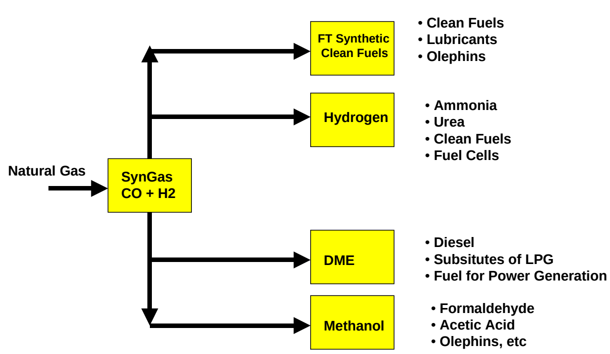


Figure 27 – Gas to Chemicals

ADDITIONAL FACTORS

Process Intensification

We indicated process intensification as a vehicle to cost reduction and new technology. Process intensification is the development of new equipment that, compared to those commonly used today, can substantially decrease the equipment size, production capacity ratio and energy consumption, ultimately resulting in less expensive technologies. Most of process intensification falls into three well-identified areas:

1) Multifunctional Reactors
   These can be described as reactors that – to enhance the chemical conversion taking place and to achieve a higher degree of integration – combine at least one more function into the reactor that conventionally would have been done on separate equipment. Reactive distillation is an example; others are static mixer reactor, heat exchange reactors and membrane reactors. Membranes can contain catalytic material. The major barrier to commercializing these systems is the large disparity between rates of reaction and permeation. For example, space times for commercial gas-phase catalytic and non-catalytic reactions are in the order of 0.1-0.5 seconds. No highly selective membrane known or projected to be developed has a permeation rate that can begin to match these rates of product formation. One major job for process engineering in the next decade will be to identify combined reaction/separation system candidates.

   Fuel cells represent another example of multifunctional reactor systems. Here, the integration of chemical reaction and electric power generation takes place.

2) Hybrid Separations

As mentioned before, many of the developments in this area involve integration of membranes with another separation technique. In membrane absorption and stripping, the membranes serve as a permeable barrier between the gas and liquid phases. By using hollow fiber membrane modules, large mass-transfer areas can be created, resulting in compact equipment. Besides this, absorption membranes offer operation independent of gas-liquid flow rates, without entrainment, flooding, channeling or foaming.

Other types of possible hybrid separations are reactive extraction, membrane distillation and adsorptive distillation.

Process Control and Safety Systems

The next 20 years will see a greater emphasis on the use of information technology in plant operations. During the past 20 years, we assisted with the emergence of the DCS systems. Now with the focus in the "enterprise computing", some DCS designers are using PCs in client server architecture rather than the hub-centric approach. This promotes the open systems and makes available a variety of object-oriented software tools, innumerable amounts of digital field equipment, valves, and other emerging devices. Neural networks have emerged in the last decade and have been investigated in applications of artificial intelligence.

On process modeling, industrial groups are beginning to examine whether is possible to achieve a seamless transition between models used for design and models used for control. This would allow users to "plug and play" company-specific libraries, such as physical properties packages, into any compliant simulator. The goal is to have models for real time control that run at 50-500 times real time. New algorithms are emerging in the industry (MPC – model predictive control).

Emerging design methods in the area of safety and plant protection are seeking to reduce cost and environmental issues (zero flaring). There are several different abbreviations that have been used:

- HIPPS, High Integrity Pressure Protection Systems
- HIPS, High Integrity Protection Shutdown Systems
- OPPS, Over Pressure Pipeline Protection System

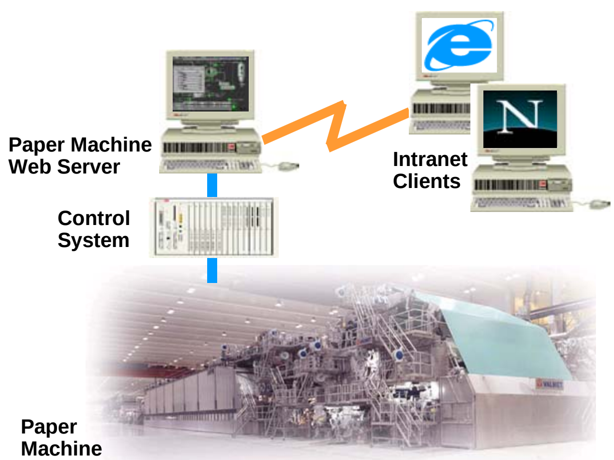
Several solutions for HIPPS are emerging for gas distribution, gas treating and liquids recovery, offshore platforms, and are also being evaluated for use in sub-sea production systems.

Engineering & Construction

In the past two decades, there has been aggressive emphasis on optimizing the execution process. Process simulations, computerized detailed design and procurement have benefited from modern computer applications. There's more coming! In the area of process design, a new generation of simulators with more dynamic simulation content will be adopted. In the next decade, the design cycle to firm up a basic design will be reduced by at least 30 percent of today's standards.

Use of virtual CAD technology will allow an important transformation of design execution. Today's design disciplines will evolve into a new "plant design" discipline, whose designers will be able to design in full virtual scale a complete module of a facility. The whole facility will be then "virtually" assembled. Each elemental constituent of a virtual design will be a virtual object that replicates the real one; "virtual" flange will "know" that it is a flange and will behave as such. Piping and structural stress analyses could be verified concurrently as the design is executed. Twenty specialized “plant designers” will do the work that today takes two hundred.

Project execution will be optimized through online procurement and e-commerce, with more acquisitions on the Internet and less paperwork, reducing the time lag for buying, expediting and delivering. More and more, projects will have global logistic execution. Fast track projects could be executed on a continuous schedule using an Internet project site *(See Fig 28 and 29).*



Business impact:

- New product through applied Web technologies
- Benefits for ABB
  - Reduce commissioning and service costs
  - New business paradigm: supply service rather than hardware
- Benefits for customer
  - Access control system from anywhere within the mill
  - Get analysis and reports from PMWS
  - Subscribe to diagnosis applications

Figure 28 – Paper Machine Web Deployment

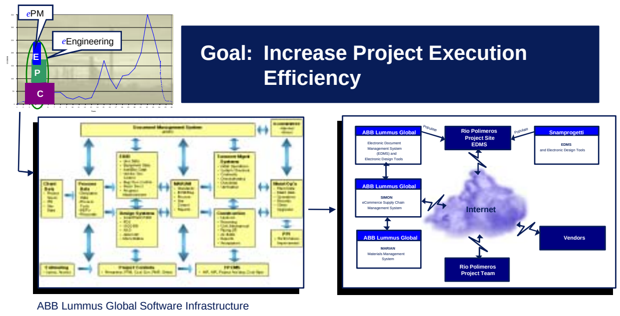


Figure 29 –ABB Lummus Global Interactive Leveraging our Knowledge Initial Developments – Project Sites

The biggest shock to the energy industry may be the impact of e-commerce and information and control technology on the ways people use energy and ensure reliability. At a minimum, "e-commerce should add transactional liquidity to each link in the energy value chain – squeezing out cost savings along the way."

Longer term, the interface of e-commerce, with sophisticated two-way metering and control technologies, can provide tools to "manage demand" by allowing end users to adjust consumption behavior to price signals in real time. This holds the potential to reinvent the gas and power industries – from the customer back upstream.

In the construction area, modularization technology will continue to play a vital role in optimizing field erection cost by increasing productivity in a controlled environment. However, local conditions will ultimately influence the final decision *(See Fig 30).*

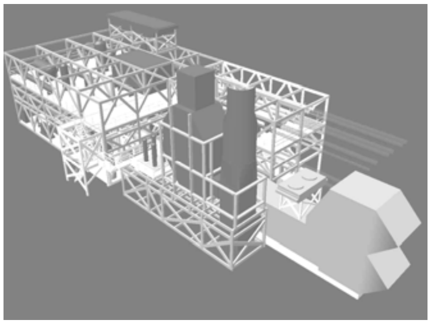


Figure 30 – Modular Construction Technology

ATTEMPTING A SUMMARY

Back to our initial question: are we reaching a mature age in gas technology? We are certainly reaching a mature stage in the understanding that technology and business go together. In the future, the technology development process will have to change to reflect this fact. What used to be the work of a lonely creator needs to become the product of a team integrated by marketing and technical experts. Technology is more than ever driven by the market…a global market.

In the same way as technology *per se* is project science, business without technology is small business thinking, and business doesn't get big by thinking small! A disappointingly common way of thinking in business is that the only way to be profitable with a technologically mature business is to reduce expenses, improve business efficiency and persevere until times gets better.

Experience says that from the moment of discovering a new method, process or technology, to the point when this technology penetrates a market successfully, has seldom been less than 10-20 years. Then any new technologies, if they are going to have major impacts on the business by 2020, will need to emerge within the next decade.

Energy costs are still considered the major contributor to the overall cost of production. Therefore energy reduction always must be studied in concert with the investment implications of that reduction. Nevertheless, energy reduction remains a legitimate field for process design efforts and research.

Business competition is ferocious, and the gas business industry is continually experiencing consolidations and mergers. Stockholders want to see companies increase revenues and grow. These have been emphasized as ways to gain economies of scale, diversify risk and enter new markets. The push to consolidate is likely to continue – first among upstream companies and then among gas and power midstream players (pipelines, power generators, etc.). Increasingly, however, this emphasis on consolidation is likely to shift to distribution. More multistate and multiregional distribution entities will emerge.

New process or equipment technology can, and must, play a decisive role in enhancing the profitability in the hydrocarbon processing industries. All aspects of process development and technology delivery must be improved to meet this challenge.

In order to be competitive in the new millennium, we need to be persistently innovative and adaptable to the new market global forces. The new technologies will have to incorporate requirements and opportunities with

- Design of more inherently safe processes
- Increase of environmental awareness
- Operational cost optimization
- A global workflow
- Deregulation of gas in North America and Europe
- Increasing use design information technology tools and advanced CAD systems

- A fantastical growth in information systems
- A push for innovative methods to convert natural gas to clean liquid fuels,
- An increasing perception that LNG offshore can be instrumental for an LNG open market

In summary, some pioneer have reached a mature stage but will continue as long as they make business sense. Some other technologies, like the cryogenic processes, will continue to be developed with more aggressive, energy efficient solutions for a global reduction of horsepower consumption and capital cost optimization via equipment design developments. The new area of focus appears to be those technologies that did not get full attention or were not completely scientifically understood e.g. adsorption in several applications, like gas treating, dehydration and gas dew point control. We have noticed that recently, some of the major gas producers have developed alliances with adsorption chemical suppliers to continue the development of adsorbents. Here is an indication that a new focus in this technology is emerging.

Another important issue to consider is that a certain technology could have been selected to carve a position of uniqueness out the control of the other technological competitive streams that could have controlled them.

We have learned more on how to develop, select and use technology. The key issues reside in understanding what are the drivers that will make these technologies acceptable, how they are adapted to the business scenario, and their performance through their whole life cycle. An economy propelled by natural gas, in an environment characterized by dynamic changes, is a good incentive to keep our innovation in motion.

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Author's Note: The concepts and ideas contained in this paper do not necessarily represent ABB Lummus Global official position in these matter.

APPENDIX I – SUMMARY TABLE

Production Segment	Traditional Technology	Emerging Technology	Advantages
Production Facilities	• Conventional Separation • Topsides Facilities	• Multiphase Rotating Eq • Two-Phase Turbines • Sub Sea Equipment	• Reduced Plot
Pipelines and Compressor Stations		• Coatings • Drag Reduction Agents • Flow Assurance • High Eff. Compression • In-Line Compression	• Lower DP • Lower HP • Simpler Facility
Inlet Gas Facilities	• Conventional Separation • Slug Catchers	• Two-Phase Turbines • In-Line Rotating Sep.	• Reduced Plot

Gas Treating	• Absorption:
	  • Chemical
	  • Physical
	• Adsorption
	• Membranes
	• Physical Separations
		• Hybrid Technologies:
		• Absorption-Diffusion
		• Diffusion-Catalysis
		• Diffusion-Adsorption
		• Cryogenic Separations
		• New Solvents
		• Advanced Adsorption
		• High Eff. Mass Transfer
		• Membranes for Hg
			• Equipment Size Reduction
			• Lower Energy Consumption
			• Reduced Corrosion

Sulfur Removal	• Modified Claus Process • Direct Oxidation • Redox-Type Solvents • Scavengers	• Adv. Direct Oxidation • Fluid Catalytic Claus • Hydrogen Sulfide Split • H_2S Reinjection	• Reduced Equip. • High Recovery • Reduced Plot • H_2 Availability • No Sulfur Prod. • Lower CAPEX
Gas Dehydration	• Glycols • Molecular Sieves (TSA) (Batch Process)	• Membranes • Hybrid Membranes-Solver • Fluidized Adsorption • Hydrate Inhibition by Magnetic Fields	• Reduced Energy • Reduced Size • Lower CAPEX
Liquids Recovery	• Mechanical Refrigeration • Turboexpander • Specialty Solvents	• Membranes • Emerging Expansion Tech • Two-Phase Expanders • Process Intensification • New Generation of Cryogenic Plants	• Reduced Equipment • Process Intensification • Reduced Energy • Lower CAPEX
Fractionation	• H& M Transfer Model • Traditional Design Method	• New Heat Transfer Model • Advanced Design Methods • Process Integration • Thermal Coupling • New Co-Current Model	• Compact Design • Energy Effcy • Lower OPEX • Lower CAPEX

Production Segment	Traditional Technology	Emerging Technology	Advantages
Product Treating	• Alkanolamines • Specialty Solvents • Scavengers • Adsorbents	• Membranes • Advanced Adsorption • Advanced Mass Transfer	• Reduced Size • Reduced Equip. • Lower CAPEX
Nitrogen Rejection	• Cryogenic Separation • Selective Solvents	• Advanced Adsorbents • Specialty Membranes	• Lower CAPEX • Reduced Plot
LNG Production	• Cascade Refrigeration • Mixed Refrigerants	• Turboexpander Cycles • Thermoacoustics • Hydrate Production	• Reduced Equip • Lower CAPEX • Offshore