EASTMAN CHEMICAL COMPANY

Gasification Plant Design and Operation Considerations from An Operator’s Perspective

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INTRODUCTION

Eastman Chemical Company’s Chemicals from Coal facility was the first commercial scale coal gasification plant in the United States. The facility, which started-up in 1983, converts approximately 1250 Tons/day of high-sulfur, Appalachian, bituminous coal to acetyl chemicals which are a major source of raw materials for the Kingsport, Tennessee manufacturing site. The acetyl chemicals and their derivatives are then sold as intermediates and eventually end up in consumer products like pharmaceuticals, photographic film, filter tow, plastic screwdriver handles, paints and coatings.

Eastman’s performance numbers have been reported on numerous times at past conferences, and so updated numbers will be presented in this paper, but not as the focal point of the presentation. Last year Eastman announced its intentions to enter the Gasification Services business, primarily operations and maintenance of gasification plants for others. As we have met with many in the industry considering gasification as an option for power, chemicals, or both, most of the talk is concentrated on capital cost, reliability, overall efficiency, and financing to name a few. These are most important to be sure, but are high-level topics that are impacted by hundreds of smaller issues. Since Eastman has a long history as an operator, we have a unique perspective on the types of issues the developer or owner of a potential plant should be considering at the next level down. These include areas such as coal/fuel selection (what’s important), environmental issues (fate of trace elements, emissions and permitting), redundancy and impact on availability, maintenance philosophy, selecting a sulfur recovery technology, corrosion/erosion issues, maintenance philosophy, water chemistry and others. All of these “minor” issues can combine to make your plant a “Clean Coal” success story or a disaster depending on how effectively they are addressed.

UPDATED OPERATING STATISTICS

Eastman’s Configuration – Figure 1

Eastman’s gasification facility utilizes two, high-pressure (1,000 psig) Texaco quench gasifiers to convert approximately 1250 Tons/day of bituminous coal into acetyl chemicals which are used in the manufacture of a wide variety of consumer products by Eastman’s customers. Sulfur and carbon monoxide are removed from the system at extremely low levels using the Rectisol® process. Sulfur is recovered using a combination of Claus and SCOT units. A Linde designed cold box is used to cryogenically separate CO from the syngas. The downstream chemical plants use purchased technology for methanol production (Air Products liquid phase and Lurgi fixed bed) and Eastman developed technology for methyl acetate, acetic acid and acetic anhydride. Only one of the gasifiers is required for normal production and one is a spare. There are several key pieces of equipment that are also spared, and in places two processing units are required for full rates, but there are no complete spare trains for any other section of the plant.
Operating Summary
The operating statistics have not changed significantly from last year, which is fortunate since they were at very high levels already. The basic measure of operation is the % on-stream time. This is the actual hours of operation divided by the number of hours in the time frame specified. Eastman’s numbers are reported for the most recent two-year maintenance cycle so that the every-other-year planned maintenance shutdown is included. From September 2000 through September 2002, the gasification block was on-stream 97.7% of the time. Of the 2.3% downtime, 1.2% of this was planned (the biannual shutdown in May 2001) and 1.1% was unplanned (Figure 2). The chemical production end of the facility cannot operate without the gasification plant operating, so it was on-stream slightly less time. There was never a time when production was not needed. So the forced outage rate is equivalent to the unplanned downtime and was 1.1%. The annual loading capacity for the two-year period was 132% of the original design rate (125% during the year with the planned shutdown and 139% the non-shutdown year). The typical daily rate is approximately 145% of the original design rate. The average time between gasifier switches is approximately 60 days YTD 2002 (Figure 3). The average run time (time between gasifier start and shutdown, regardless of whether it is switched or re-started) has also been climbing over the years and is around 35 days (Figure 4). There are numerous causes for shutdowns, but the ultimate limiting factor on a run had been the life of the feed injector. A breakthrough was made around 1996 with an innovative idea in feed injector design. Using our latest design, a record run of 122 days was achieved this past spring.

DESIGN & OPERATIONAL CONSIDERATIONS - AN OPERATOR’S PERSPECTIVE

Now let’s look at some of the second level design and operating issues that developers and potential owners should be considering in addition to the major issues such as financing, overall economics, and efficiency. Since the economics for IGCC will continue to be tight for the foreseeable future, it will be the summation of all of the smaller issues that can make or break a project. These are issues that have solutions but if not addressed up-front in engineering design or through sound management and operating techniques, then they could add up to an economic disaster. As the saying goes, “the Devil is in the details.”

Feed Choice
The most basic consideration is the coal or other carbonaceous feed choice. The obvious considerations such as price, Btu value, sulfur content, ash content, availability and transportation readily come to mind. But there is more to it than that. For example, the ash behavior is critical to the operation of a slagging gasifier. Figure 5 is a graph of viscosity versus temperature for two unmodified coals. Both coals have exactly the same ash fusion point as reported by the standard laboratory procedure. However, these would perform much differently in the gasifier. The ash with the sharper curvature would be very difficult to run without high refractory wear. The ash with the more gradual slope would be much more forgiving and could be run at much lower temperatures. In most cases the coals can be modified to make them approximate the desired behavior. If low ash petroleum coke is used as the feed, then a fluxant must be added to ensure that the heavy metals are flushed out and encapsulated or vitrified in the slag.
Another consideration in choosing a feed source is the impact of trace minerals. Coal contains essentially the entire periodic table of elements at some concentration level. Most of these are in very small quantities and in the case of a slagging gasifier are vitrified in the non-hazardous slag. However, there are a few that need special consideration such as chlorides, arsenic, nickel, mercury and vanadium. The amount of these will impact your decisions around plant metallurgy, equipment fouling factors, catalyst life, solids handling and disposal, water discharge, and personal protective equipment just to name a few. For example, high chlorides or restrictions on water blow down from the plant resulting in the build-up of chlorides will limit the options of stainless steel piping and parts in the water system due to chloride stress corrosion cracking. Vanadium is troublesome, particularly in petroleum coke applications, since the concentration is usually high and vanadium has a very different melt point at normal gasifier operating conditions versus the oxidizing environment present during preheat or during startups and shutdowns. Consistency of the physical properties is also a key. Frequent variations in the feed will require a wider operating range in terms of temperature, the O/C ratio, slurry concentration, etc., and may result in less efficient operation (lower conversion, more CO₂) and increased maintenance cost (refractory wear). Other considerations especially for coals are the slurry additives, slurry solids concentration achievable vs. desired, choice of fluxants and the resulting impact on water chemistry, grind distribution and its effect on the slurry properties and carbon conversion. All coals are not created equal, but gasifiers are very flexible and can accept a wide range of possibilities as long as the important characteristics of the coal or other feed stream are understood and accounted for.

Environmental Issues
Getting the permit for any kind of coal-based plant is a long and difficult process. But the granting of the permit is just the beginning. Next you need to think about how you are going to comply with that permit. Title V regulations that were mandated in 1990 and became effective in the mid to late 1990s have some particularly troublesome aspects. Now instead of just calculating that the theoretical emissions ought to be lower than the permit levels, the operators are required to prove they are in compliance. In addition, it is incumbent on the owner to self report any violations, and there is personal accountability for those in charge of the facility. Penalties and fines are much heavier than in the past. All of this leads to the conclusion that you had better have a very good system of compliance monitoring. One of the tools we use at Eastman is our distributive control system to monitor the critical parameters. Operators and management are automatically alerted to any upsets impacting environmental regulations via alarms directly from the control system, e-mail notes, and pagers. Reports are carefully constructed to give managers the information required without flooding them with insignificant minutia. It is essential that the appropriate people who are now much more accountable have timely access to meaningful environmental information.

There are several environmental issues beyond the basic permit that must be considered. An area of concern that has received more and more attention from regulators recently is the flaring of raw syngas containing sulfur during startups. The problem is that since the basic product is a gas and difficult to store, all of the units are started in sequence so that there is a time when the gasifier is producing raw gas, but the sulfur recovery unit is not yet running. During this time the raw gas is flared to the atmosphere. The overall emissions of the plant are therefore increased.
making it less environmentally friendly and more difficult to permit. This is particularly troublesome during the early years when startups are very frequent. There is another way. Several years ago, Eastman developed a patented technique to start the gasifier and sulfur recovery units up on a sulfur-free, liquid fuel and then transition to the normal slurry feed without interruption. This avoids the flaring of raw syngas during startup and reduces total SO$_2$ emissions.

Another hot topic in the environmental arena, especially for coal-based power plants, is what to do about mercury. There is pending legislation that, if passed, will result in significant restrictions on previously unregulated mercury emissions for power plants. This concern will actually play in gasification’s favor when compared to other coal-based technologies. Because some of the products from Eastman’s gasification plant are raw materials to the photographic industry, we have been sensitive to mercury from the very beginning. Mercury is removed from the syngas using relatively small absorbent beds that trap the mercury at a 90+ % removal rate. The bed operates at 1,000 psig, and approximately 30 Deg. C. The carbon bed material is changed out every 12 – 18 months based on fouling and pressure drop, not mercury loading. Eastman has been doing mercury removal from our syngas for almost 20 years now in a very effective and economical way.

Arsenic is contained in coal at part per million quantities. Even though it is a metal, it is volatile at the conditions present in the gasifier. Because of this, a significant portion of the arsenic exits the gasifier with the raw syngas and then precipitates in various places throughout the cooling train causing exchanger plugging and catalyst poisoning. Arsenic is a hazardous material and special precautions have to be taken when cleaning or maintaining equipment in these areas of the plant, for both environmental and safety reasons.

**Acid Gas Removal Technology**

The choice of acid gas removal technology is a very basic decision that must be made early in the project. The decision depends on the permit levels required and the syngas end use. For example, at Eastman, we use Rectisol technology for very deep removal of sulfur and CO$_2$, because our end use for the syngas is chemical production that involves cryogenic separation and sensitive catalysts. The sulfur level in the syngas from Eastman’s Rectisol system is less than 1 ppm with total sulfur removal and capture at 99+ %. Power production applications, where permitting will allow, may choose a less intensive removal process such as Selexol or ambient MDEA systems. As you can imagine, the capital and operating cost go up as the sulfur removal capability goes up. So, pick your sulfur emissions target and read the price, right? Well, it’s not quite that simple. The sulfur loading capacity of a given system depends on the sulfur and CO$_2$ content of the gas as well as the system pressure. Generally speaking, the chemical solvents like MDEA are more efficient at lower pressures, but the physical solvents like methanol in a Rectisol process are more efficient at higher pressures.

**Process Safety Management**

Safety is a very important consideration, both process safety and personal safety. Eastman’s safety record at the gasification complex has been excellent, with a long-term OSHA recordable rate of around 1.0. This is in the upper quartile of the chemical industry. In fact the gasification
plant has had only one OSHA recordable injury in the last 3 years. The last injury that required a
day away from work was eleven years ago and was not related to the process (a turned ankle).
So it can be done, but it requires diligence and commitment. It takes a comprehensive Process
Safety Management program. Eastman uses a behavioral based system as the primary means of
ensuring safe practices by everyone at the plant. The most basic concern is personal protective
clothing and equipment. Some examples of these are the fire protection suits used by mechanics
to change out the feed injector while the unit is still hot. Syngas containing CO and H₂S is
highly toxic, and when H₂S has been taken out, the syngas is also odorless. The gas is processed
at very high pressures increasing the potential for leaks. Because of the potential dangers, all
Eastman operators wear personal CO and H₂S monitors that will alert them to potentially
hazardous concentrations of those gases. Area monitors are also strategically located throughout
the buildings.

Process safety is an extension of personal safety but has more to do with equipment design,
training, and safe work processes. An example would be Eastman’s management of change
process. This process ensures that any changes to the process have been thoroughly reviewed,
documented (procedures and drawings), and affected people have been trained. Major changes
go through a rigorous Process Hazard Analysis to ensure safe operation.

Training is also an important aspect of Process Safety Management. There are two basic types
of training for operations employees. First is the initial Apprenticeship training that all operators
and mechanics receive before they are certified. The operator program, for example, is certified
by the U. S. Bureau of Apprenticeship Training and requires approximately 3 years to complete.
The program includes a general education on pumps, valves, instruments, and processing
equipment as well as job specific training on all of the individual tasks required to be a fully
competent gasifier operator. But an operator’s initial training is not the end of learning--this will
continue for a career. First, there is mandatory safety training from fire extinguisher use to
emergency evacuation and environmental inspection and response. But process refresher
training is also needed and even required by OSHA. This is even more important as the plant
runs more reliably and upsets (or training opportunities) are less frequent. At Eastman, the
experienced operators follow a 3-year schedule of training. Each month will have a mix of
process training and safety or environmental training.

Another aspect of a good Process Safety Management System is a mechanical integrity program.
Monitoring and tracking representative points throughout the process using thickness gauges, X-
ray, and visual inspections will identify potential failure points before the failure occurs. When
the process contains high-pressure, toxic gases, this is most important. Also, good record
keeping and analysis along with a good knowledge of the fundamentals of the process are needed
so that the right areas are inspected and critical areas are not missed, but without excessive
inspection costs.

Redundancy
Redundancy is a great equalizer when individual pieces of equipment or systems are unreliable,
but it can also be a crutch or an excuse to allow poor performance. Redundancy is expensive.
The amount of redundancy needed will not be the same for every project since some applications
require different overall reliabilities. However, a project will never be able to afford the
indiscriminate application of redundancy over the entire system. Your redundancy capital must be spent wisely. Intelligent redundancy is based on data, on a criticality ranking of equipment, on performance history, and is targeted to specific areas. An example of smart redundancy would be a spare quench water pump since these pumps are known to have a short mean time to failure and are absolutely essential to the operation. Another example might be a set of exchangers that are known to foul frequently, must be cleaned after every run (and sometimes during a run), and cannot be bypassed. An example of not-so-smart redundancy is to spare full gasifier trains from slurry prep through gas cooling when only a few of the items have a history of poor reliability. Spending capital for spares that are configured in a way so that they cannot be switched quickly is also an example of unwise use of redundancy capital. Capital is precious. Spend it wisely.

While we are on the topic of redundancy, the redundancy question most frequently asked is how many gasifiers should I have to give me X % availability. Reliability and availability are high-level concerns for the industry. Eastman utilizes a system that has one gasifier and one spare. The cooling train and water system are single train with specific pieces spared. As we have thought about the business of operating IGCC plants for others, this has certainly come up in our minds. So we enlisted the help of some Eastman statisticians to develop a statistical simulator using third party software (Promodel®) for gasifier trains. The problem is a little more complex than the straight probability question of what percentage of the time will I have Y gasifiers running if I have X total. Spares, when utilized, are only run when needed and have varying turnaround times and other complex issues. The model we developed takes some very basic inputs such as number of gasifiers, average run time, refractory life, turnaround time, percent of the time the gasifier is re-fired instead of turned around, etc., with appropriate standard deviations. Then the model takes this data and simulates the system running over a timeframe of 10-15 years to get a statistical prediction of the output of the plant as total system output and % of the time at full rate. The % time at full rate is very different than the total output and is especially important for power plants where the product (electricity) cannot be stored. The model also has a feature that would allow individual gasifiers to ramp up in rate when one goes down to help compensate for the temporary loss of production. This model will be a great tool in predicting performance and evaluating redundancy on a macro scale. One example of how this data might be used would be an analysis of the effect of gasifier average run time on overall system reliability when a spare is utilized. The example is for a 3 of 4-gasifier system (Figure 6). The plot generated shows (assuming everything else is unchanged) that the overall output and the % time at max rate have steep curves at low run times which is expected, but the curves start flattening out around 40 to 50 days, with no significant benefits after that point (not counting maintenance benefits). So in design and operation of the plant, clearly the target should be around 40 to 50 days, but extra redundancy or expense to get more than 50 days may not be worth it.

Another example of the use of this model would be a plot of system output vs. individual gasifier availability (Figure 7). At an individual gasifier availability of 85%, a 5 out of 6 system would yield approximately 92% of the maximum output over a year and would be at full rate 75% of the time for the gasification block (ASU through gas clean-up, including planned and unplanned outages). In systems with fewer gasifiers, the spare becomes more dominant and the statistics (especially % time at full rate) increase significantly.
There are literally hundreds of permutations that can be considered and quickly simulated by the model.

**Maintenance Philosophy**

The first decision to make concerning maintenance is the culture and mindset you want to establish. Will it be a culture that reacts to failures or one that plans for success? Often, this decision is made by default for the reactionary mode. Eastman utilizes a concept known as reliability based maintenance. RBM is a combination of expertise, work practices, training, and technology that has resulted in a 30% reduction in maintenance costs at the Kingsport plant site over the last 5 years.

Then the question arises about staffing structure. How much should be in-house, and how much contracted? Should it be days only or full shift coverage? Should mechanic and operator skills be combined into the same person? There are numerous examples of philosophies that cover the entire range, but Eastman would recommend a balanced approach. The use of contract maintenance is advantageous due to the lower costs and flexibility of resources. However, a certain amount of in-house expertise needs to be developed and retained for complicated and critical pieces of equipment. An example of this at Eastman would be the carbon monoxide compressors. The maintenance of these large critical pieces is done by Eastman mechanics so that the expertise can be developed over time and does not depend on the stability of the contracting company. The same arguments would apply to the level of multi-skilled (maintenance plus operations) employees. Eastman has dedicated and separate maintenance and operator organizations, but there are areas of overlap. For example, operators frequently do routine maintenance like changing gaskets or “pulling” a breaker, but would never try to do a pump laser alignment. The need for flexibility among all employees versus deep expertise in a few people must be weighed and balanced.

Equipment reliability determines the maintenance work schedule, not the desires of the manager. If individual pieces of equipment are unreliable, then in order to maintain reasonable system reliability, a significant force of mechanics is going to be necessary around the clock. If equipment is more reliable, then a large portion of the work can be planned and done in daylight hours with a more concentrated and efficient workforce. The Eastman gasification facility has transitioned from almost entirely shift maintenance in the early years to much more planned maintenance on days. As a result of this and the underlying improvements in reliability, the maintenance costs for the plant have continued to drop (20% over the last 4 years) while the overall availability and output have remained steady or improved.

**CONCLUSION**

There are many other considerations in designing and operating a gasification facility, although the ones identified in this paper are some of the most important, they barely scratch the surface. All of these “details” can be frightening, but they can be addressed in cost effective and efficient ways. How these details are managed can make or break a project, particularly in this time of extremely tight economics. Eastman has effectively dealt with all of these issues through the nearly 20 years of operation and can offer proven advice on how it can be done in your plant as well.
Figure 1 – Eastman’s Chemical’s from Coal Configuration

Gasification Basics

Eastman’s Configuration

Coal

Oxygen

Syngas

CO$_2$ H$_2$S Removal

Particulate Removal

Tar and Oil Gasifier

Steam

Sulfur Recovery

SCOT-Clave

CO

CO$_2$ Separation (Linde)

Chemicals

Ag, NO, MoO$_3$, MoO$_4$

Sulfur

Solids Co-products

Figure 2 – Operating Statistics

Eastman Operating Statistics

09/2000 - 09/2002

On stream 97.73 %

Planned 1.16%

Unplanned 1.11%

Not needed 0.0%
Figure 3 – Time Between Gasifier Switches

Figure 4 – Time between Gasifier starts (includes re-starts)
Figure 5 – Example Coal Ash Viscosity Curves

![Slag Viscosity vs Temperature](image)

Figure 6 – Results of Statistical Model

![Availability vs run time](image)
Figure 7 – Results of Statistical Model

System (5 of 6) Output vs. Individual Gasifier Availability
Gasifier Block Only (no ramp-up capacity)

Total System Output, % of Design

Overall Output
% Time @ Full Rate

Individual Gasifier Block Availability
(Includes planned and unplanned downtime)