

**COMMERCIAL-SCALE DEMONSTRATION
OF THE LIQUID PHASE METHANOL (LPMEOH™) PROCESS:
OPERATING EXPERIENCE UPDATE**

Barry W. Diamond (diamonbw@apci.com; 610-481-5944)

Edward C. Heydorn (heydorec@apci.com; 610-481-7099)

Peter J. A. Tijm (tijmpj@apci.com; 610-481-0531)

Air Products and Chemicals Inc.
Allentown, Pennsylvania, USA

Barry T. Street (btstreet@eastman.com; 423-229-6062)

Eastman Chemical Company
Kingsport, Tennessee, USA

Robert M. Kornosky (kornosky@fetc.doe.gov; 412-892-4521)

U. S. Department of Energy
Federal Energy Technology Center
Pittsburgh, Pennsylvania, USA

ABSTRACT

The Liquid Phase Methanol (LPMEOH™) process uses a slurry bubble column reactor to convert synthesis gas (syngas), primarily a mixture of carbon monoxide and hydrogen, to methanol. Because of its superior heat management, the process can utilize directly the carbon monoxide (CO)-rich syngas characteristic of the gasification of coal, petroleum coke, residual oil, wastes, or other hydrocarbon feedstocks. When added to an integrated gasification combined cycle (IGCC) power plant, the LPMEOH™ process converts a portion of the CO-rich syngas produced by the gasifier to methanol, and the unconverted gas is used to fuel the gas turbine combined-cycle power plant. In addition, the LPMEOH™ process has the flexibility to operate in a daily load-following pattern, coproducing methanol during periods of low electricity demand, and idling during peak times. Coproduction of power and methanol via IGCC and the LPMEOH™ process provides opportunities for energy storage for electrical demand peak shaving, clean fuel for export, and/or chemical methanol sales.

Since start-up in April 1997, performance of the LPMEOH™ Process Demonstration Plant has exceeded expectations. Following commissioning and shakedown activities, the first production of methanol from the plant occurred on April 2, 1997. Nameplate capacity of 260 tons per day (TPD) was reached for the first time on April 6, 1997, and production rates of over 300 TPD of methanol have been achieved. Several key milestones were achieved during 1998, including an

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availability of over 99%. Since startup, over 35 million gallons of methanol have been produced at the LPMEOH™ Process Demonstration Plant, and plant availability has exceeded 96%.

This paper provides a description of the LPMEOH™ process, the commercial applications for the technology, and an update of the current plant performance results at the Kingsport site.

I. INTRODUCTION

The LPMEOH™ technology was developed during the 1980's with the financial support of the United States Department of Energy (DOE). The concept was proven in over 7,400 hours of test operation in a DOE-owned, 10 tons-per-day (TPD) Process Development Unit (PDU) located at LaPorte, Texas.¹ The first commercial-scale demonstration plant for the technology was sited at Eastman Chemical Company's (Eastman's) coal gasification facility in Kingsport, Tennessee, with the help of a \$92.7 million award under the DOE's Clean Coal Technology Program. Construction began in October of 1995 and concluded in January of 1997. After commissioning and startup activities were completed, operation began in April of 1997. During a four-year operating program, the LPMEOH™ Process Demonstration Plant will demonstrate the production of at least 260 TPD of methanol, and will simulate operation for the integrated gasification combined cycle (IGCC) coproduction of power and methanol application. The test plan will also seek to establish commercial acceptance of the technology and verify the fitness of the methanol product through a series of off-site, product-use tests. Total cost of the project, including the four-year demonstration test program, is forecast at \$213.7 million.

Air Products and Chemicals, Inc. (Air Products) and Eastman formed the "Air Products Liquid Phase Conversion Co., L.P." partnership to execute the project and own the LPMEOH™ Demonstration Plant. Air Products manages the overall program and provides technology analysis and direction for the demonstration. Air Products also provided the design, procurement, and construction of the plant (i.e., a turnkey facility). Eastman provides the host site, acquired the necessary permits, operates the demonstration plant, supplies the supporting auxiliaries and the synthesis gas (syngas), and takes the product methanol. Most of the product methanol is refined to chemical-grade quality (99.85 wt% purity) via distillation and used by Eastman as chemical feedstock elsewhere in their commercial facility. A portion of the product methanol has been withdrawn prior to purification (about 98 wt% purity) for use in off-site, product-use tests.

This paper reviews: the **Commercial Application** for the LPMEOH™ process technology; the **Demonstration Plant - Test Plans**, highlighting the operational plans to confirm the commercial application; and, the **Demonstration Plant - Current Performance Results**, highlighting the operating results achieved during the second year of operation.

II. COMMERCIAL APPLICATION

Technology Description

The heart of the LPMEOH™ process is the slurry bubble column reactor (Figure 1).

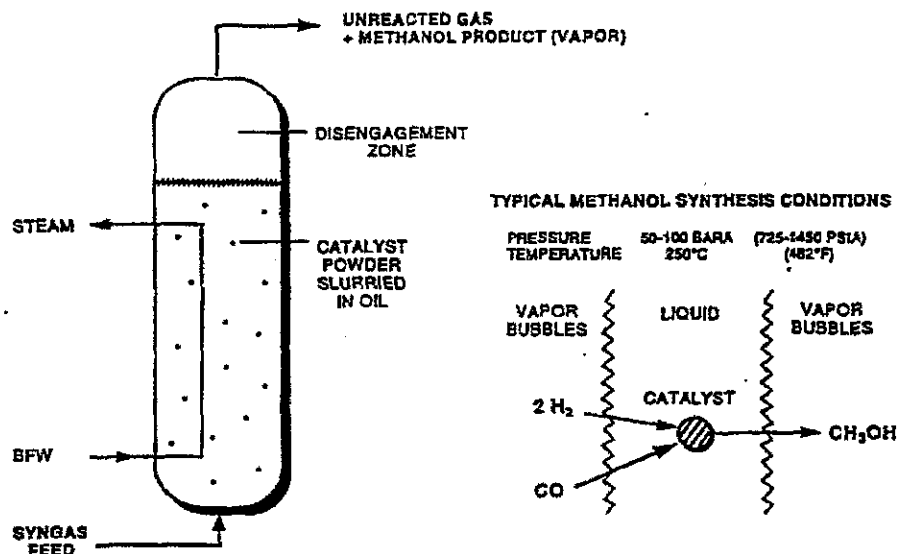


Figure 1. LPMEOH™ Reactor and Reaction Schematics

Conventional methanol reactors use fixed beds of catalyst pellets and operate in the gas phase. The LPMEOH™ reactor uses catalyst in powder form, slurried in an inert mineral oil. The mineral oil acts as a temperature moderator and a heat removal medium, transferring the heat of reaction from the catalyst surface via the liquid slurry to boiling water in an internal tubular heat exchanger. Since the heat transfer coefficient on the slurry side of the exchanger is relatively large, the heat exchanger occupies only a small fraction of the cross-sectional area of the reactor. As a result of this capability to remove heat and maintain a constant, highly uniform temperature through the entire length of the reactor, the slurry reactor can achieve much higher syngas conversion per pass than its gas-phase counterparts.

Furthermore, because of the LPMEOH™ reactor's unique temperature control capabilities, it can *directly* process syngas that is rich in carbon oxides (carbon monoxide and carbon dioxide). Gas-phase methanol technology would require that similar feedstocks undergo stoichiometric adjustment by the water gas shift reaction, to increase the hydrogen content, and subsequent carbon dioxide (CO₂) removal. In a gas-phase reactor, temperature moderation is achieved by recycling large quantities of hydrogen (H₂)-rich gas, utilizing the higher heat capacity of H₂, as compared to carbon monoxide (CO). Typically, a gas-phase process is limited to about 16% CO in the reactor inlet, as a means of constraining the conversion per pass to avoid excess heating. In contrast, for the LPMEOH™ reactor, CO concentrations in excess of 50% have been tested in the laboratory, at the PDU in LaPorte, and at the LPMEOH™ process demonstration plant without any adverse effect on catalyst activity.

A second distinctive feature of the LPMEOH™ reactor is its robust character and flexibility. The slurry reactor is suitable for rapid ramping, idling, and even extreme stop/start actions. The thermal moderation provided by the liquid inventory in the reactor acts to buffer sharp transient operations that would not normally be tolerable in a gas-phase methanol synthesis reactor. This characteristic is especially advantageous in the environment of electricity demand load-following in IGCC facilities.

A third differentiating feature of the LPMEOH™ process is that a high quality (generally greater than 97% purity) methanol product is produced directly from syngas rich in carbon oxides. Gas-phase methanol synthesis, which must rely on H₂-rich syngas, yields a crude methanol product with 4% to 20% water by weight. The product from the LPMEOH™ process, using CO-rich syngas, typically contains only 1% water by weight. As a result, raw methanol coproduced in an IGCC facility would be suitable for many applications at a substantial savings in purification costs. The steam generated in the LPMEOH™ reactor is suitable for purification of the methanol product to a higher quality or for use in the IGCC power generation cycle.

Another unique feature of the LPMEOH™ process is the ability to withdraw spent catalyst slurry and add fresh catalyst on-line periodically. This facilitates uninterrupted operation and also allows perpetuation of high productivity in the reactor. Furthermore, choice of replacement rate permits optimization of reactor productivity versus catalyst replacement cost.

IGCC Coproduction Options

The LPMEOH™ process is a very effective technology for converting a portion of an IGCC electric power plant's coal-derived syngas to methanol², as depicted in Figure 2. The process has the flexibility to handle wide variations in syngas composition. It can be designed to operate in a continuous, baseload manner, converting syngas from oversized gasifiers or from a spare gasifier. Alternatively, the process can be designed to operate only during periods of off-peak electric power demand, consuming a portion of the excess syngas and reducing the electricity output from the combined-cycle power unit. In this scenario, the gasification unit continues to operate at full baseload capacity, so that the IGCC facility's major capital asset is always fully utilized.

In either baseload or cycling operation, partial conversion of between 20% and 33% of the IGCC plant's syngas is optimal, and conversion of up to 50% is feasible. The required degree of conversion of syngas, or the quantity of methanol relative to the power plant size, determines the design configuration for the LPMEOH™ plant. In its simplest configuration, syngas at maximum available pressure from the IGCC power plant's gasifier system passes once-through the LPMEOH™ plant and is partially converted to methanol without recycle, water-gas shift, or CO₂ removal. The unreacted gas is returned to the IGCC power plant's combustion turbines. If greater syngas conversion is required, different plant design options are available.³

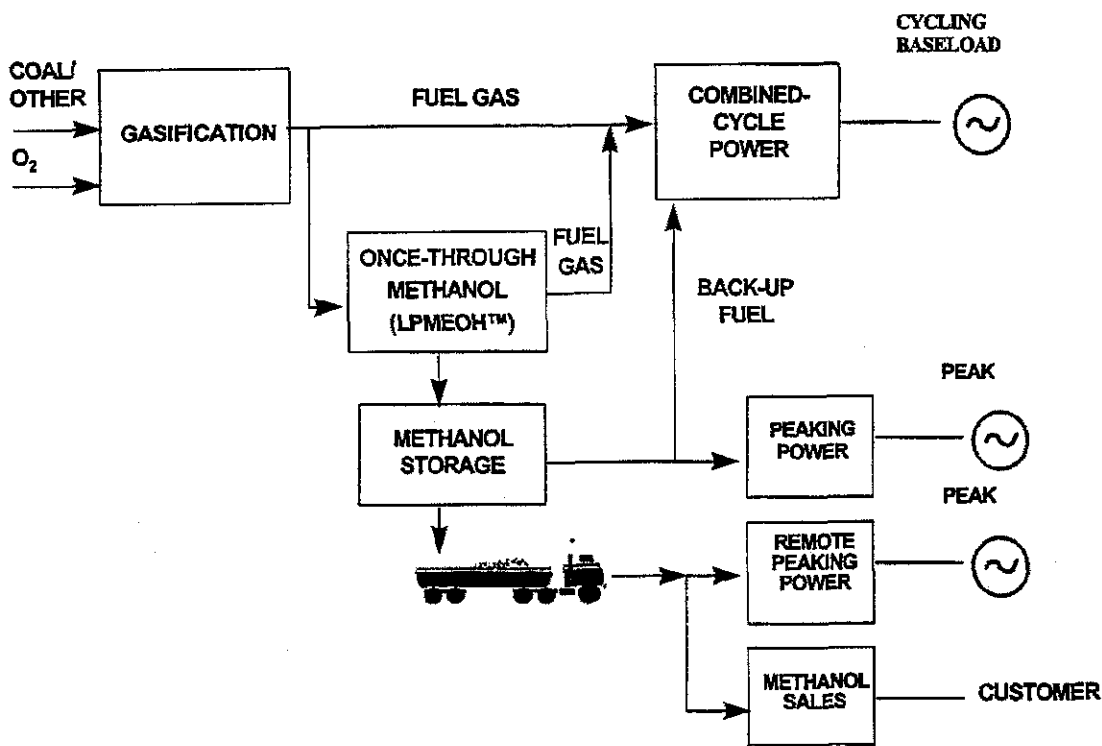


Figure 2.
Once-through Methanol Coproduction with IGCC Electric Power

Economics for Baseload Coproduction of Methanol and Power

Design studies for the LPMEOH™ process have focused principally on the aforementioned IGCC applications. A comparison of the cost of methanol as produced from the LPMEOH™ Process and from a conventional gas phase process as applied to a generic 500 TPD methanol plant as part of an IGCC coproduction facility was performed.⁸ The cost of methanol is calculated as the sum of three terms: the methanol conversion cost (which includes the fixed and operating costs for the methanol unit), the distillation cost to produce fuel grade methanol, and the syngas cost from the IGCC facility. A proprietary cost estimation screening program was used to calculate the methanol conversion cost and the distillation cost from the LPMEOH™ Process and the gas phase process for various syngas supply pressures and on-stream factors. Based on this analysis, the methanol conversion cost from the LPMEOH™ Process is \$0.02 to \$0.07 per gallon lower than from the gas phase methanol process depending on syngas supply pressure and composition and facility on-stream factor.

The LPMEOH™ Process can directly convert coal-derived syngas which is rich in CO, to produce a crude methanol product with nominally about 1 wt% water. Whereas, gas phase methanol synthesis results in a crude methanol product with 2-20 wt% water, depending on the amount of CO₂ in the syngas which is converted to methanol and water. This results in lower

purification cost for the LPMEOH™ process for the applications where high purity distillation is not required, such as Fuel Grade and MTBE Grade products.

Methanol coproduction, by IGCC and the once-through LPMEOH™ Process, does not require large methanol plant sizes to achieve good economies of scale. The gasification plant is necessarily at a large economical scale for power generation, so the syngas manufacturing economies are already achieved. Methanol storage and transport economies are also achieved by serving local markets, and realizing freight savings over competing methanol, which is usually shipped from the U. S. Gulf Coast.

III. DEMONSTRATION PLANT - TEST PLANS

The preceding Commercial Application section highlighted the advantages of the LPMEOH™ Process as part of an IGCC electric power generation system. To confirm these commercial advantages during operations, the demonstration test plan incorporates, but is not limited to, the following commercially important aspects of IGCC integration:

- Syngas compositions will vary with the type of gasification process technology and feedstock used in the power generation application. Therefore, operation over a wide variety of syngas compositions will be demonstrated.
- Catalyst life, operating on coal-derived syngas, must be demonstrated over a long period of time. Major parameters include reactor operating temperature, concentration of poisons in the reactor feed gas, and catalyst aging and attrition.
- Reactor volumetric productivity must be optimized for future commercial designs. Parameters include: high inlet superficial velocity of feed gas, high slurry catalyst concentration, maximum expanded slurry level, and removal of the heat of reaction.
- Methanol Product, as produced by the LPMEOH™ reactor from syngas rich in carbon oxides, must be suitable for its intended uses. Off-site methanol product-use testing will confirm the product specifications needed for market acceptability.

Although generation of electric power is not a feature of the demonstration project at Kingsport, the demonstration test plan is structured to provide valuable data related to the following:

- coproduction of electric power and value-added liquid transportation fuels and/or chemical feedstocks from coal. This coproduction requires that the partial conversion of syngas to storable liquid products be demonstrated.
- energy load-following operations that allow conversion of off-peak energy, at attendant low value, into peak energy commanding a higher value. This load-following concept requires that on/off and syngas load-following capabilities be demonstrated.

Three key results will be used to judge the success of the LPMEOH™ Process demonstration during the four years of operational testing:

- resolution of technical issues involved with scaleup and first time demonstration for various commercial-scale operations;
- acquisition of sufficient engineering data for future commercial designs; and,
- industry or commercial acceptance.

The demonstration test plan provides flexibility to help meet these success criteria. Annual operating plans, with specific targeted test runs, will be prepared, and revised as necessary. These plans will be tailored to reflect past performance, as well as commercial needs. The LPMEOH™ operating test plan outline, by year, is summarized in Table 1.

The demonstration test plan encompasses the range of conditions and operating circumstances anticipated for methanol coproduction with electric power in an IGCC power plant. Since Kingsport does not have a combined-cycle power generation unit, the tests will simulate the IGCC application. In addition, the test program will emphasize test duration. The minimum duration for a test condition, apart from the rapid ramping tests, is 2 weeks. Numerous tests will have 3 to 6 week run periods, some 8 to 12 weeks, and a few key basic tests of 20 to 30 weeks.

The ultimate goal of the demonstration program is to reach a stable, optimized operating condition, with the best combination of the most aggressive operating parameters. These parameters, such as reactor superficial gas velocity, slurry concentration, and reactor level, will allow maximum reactor productivity to be achieved. Debottlenecking limitations of the demonstration plant will be an on-going goal during the demonstration program.

Table 1. LPMEOH™ Demonstration Test Plan Outline	
Accomplishments:	
<u>1997</u>	Catalyst Aging Catalyst Life vs. LaPorte process development unit and Lab Autoclaves Process Optimization / Maximum Reactor Productivity Catalyst Slurry Concentration (increasing to 40 wt%) Reactor Slurry Level Catalyst Slurry Addition Frequency Gas Superficial Velocity Long-term Continuous Test Period - 31 days Establishment of Baseline Condition
<u>1998</u>	Catalyst Attrition/Poisons/Activity/Aging Maximum Catalyst Slurry Concentration (exceeding 40 wt%) Alternative Catalyst Long-term Continuous Test Periods - 65 and 94 days 99.7 % Availability
Future Work:	
<u>1999 - 2001</u>	Catalyst Slurry Addition and Withdrawal at Baseline Condition Tests Continued Catalyst Attrition/Poisons/Activity/Aging Simulation of IGCC Coproduction for: <ol style="list-style-type: none"> 1. Syngas Composition Studies for Commercial Gasifiers Texaco, Shell, Destec, British Gas/Lurgi, Other Gasifiers 2. IGCC Electrical Demand Load-Following: Rapid Ramping, Stop/Start (Hot and Cold Standby). 3. Additional Industry User Tests Maximum Throughput/Production Rate Temperature Programming In-Situ Catalyst Activation (under evaluation) Stable, extended Operation at Optimum Conditions Potential Liquid-Phase Dimethyl Ether (LPDMET™) Test

IV. DEMONSTRATION PLANT - PERFORMANCE RESULTS

Kingsport Site

Eastman began coal gasification operations at Kingsport, TN in 1983. Texaco gasification converts about 1,000 tons-per-day of high-sulfur, Eastern bituminous coal to syngas for the

manufacture of methanol, acetic anhydride, and associated products. Air Products provides the oxygen for gasification by a pipeline from an over-the-fence air separation unit. The crude syngas is quenched, partially shifted, treated for acid gas removal (hydrogen sulfide, carbonyl sulfide, and CO₂) via Rectisol, and partially processed in a cryogenic separation unit to produce separate H₂ and CO streams. The H₂ stream is combined with clean syngas to produce stoichiometrically balanced feed for a conventional gas-phase methanol synthesis unit, which is further polished in an arsine- and sulfur-removal guard bed. The methanol product reacts with recovered acetic acid to produce methyl acetate. Finally, the methyl acetate reacts with the pure CO stream to produce the prime product, acetic anhydride (and acetic acid for recycle).

Because the gasification facility produces individual streams of clean balanced syngas (Balanced Gas), CO (CO Gas), and H₂-rich gas (H₂ Gas), the LPMEOH™ Demonstration Plant design includes the capability to blend these streams into a wide range of syngas compositions. This flexibility enables the plant to simulate the feed gas composition available from any commercial gasifier.

Process Description

Figure 3 shows a simplified process flow diagram of the LPMEOH™ Demonstration Plant. Approximately half of the Balanced Gas fresh feed to the existing methanol unit is diverted to the LPMEOH™ Demonstration Plant, where it combines with the high-purity CO Gas and passes through an activated carbon guard bed. This bed removes iron and nickel carbonyls, which are poisons to methanol synthesis catalyst, down to ppb levels. The third feed stream, H₂ Gas, is the hydrogen-rich purge exiting the existing methanol unit. Since the H₂ Gas is at lower pressure than the other two feed streams, it is combined with the Recycle Gas stream, made up of unconverted syngas from the LPMEOH™ reactor, and compressed in the recycle compressor.

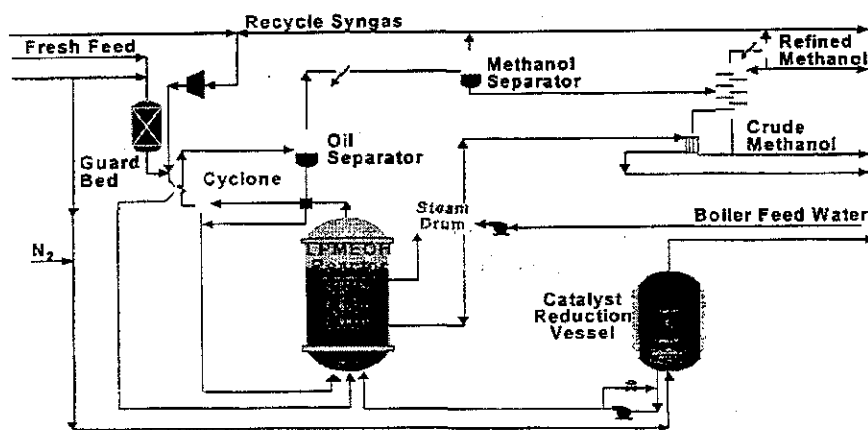


Figure 3
LPMEOH™ Demonstration Plant Simplified Process Flow Diagram

These two pairs of streams are then combined to form a single high pressure reactor feed gas stream that is preheated in the feed/product economizer against the reactor effluent. The feed gas is then sparged into the LPMEOH™ reactor, where it mixes with the catalyst slurry and is partially converted to methanol vapor, releasing the heat of reaction to the slurry. The slurry temperature is controlled by varying the steam temperature within the heat exchanger tubes, which is accomplished by adjusting the steam pressure.

Disengagement of the effluent gas (methanol vapor and unreacted syngas) from the catalyst/oil slurry occurs in the freeboard region of the reactor. Any entrained slurry droplets leaving the top of the reactor are collected in the cyclone separator. The product gas passes through the tubeside of the feed/product economizer, where it is cooled against the reactor inlet gas stream. Any condensed oil droplets are collected in the high-pressure oil separator and then returned to the reactor with the entrained slurry from the cyclone separator.

The product gas is cooled further in a series of air-cooled and cooling water exchangers, whereupon the product methanol condenses and collects in the high pressure methanol separator. Most of the unreacted syngas returns to the reactor after undergoing compression in the recycle compressor. The balance of the unreacted syngas is purged to the Eastman fuel gas system.

The condensed methanol contains dissolved gases, water, trace oil, and some higher alcohols. These impurities are removed in a two-column distillation train that produces a methyl acetate-grade methanol feed product. The bottom draw from the second column is a crude methanol stream heavy in higher alcohols, water, and any oil carried over from the reactor. This stream is sent to the existing distillation system for recovery of the methanol and disposal of the byproducts. Stabilized, fuel-grade methanol for off-site product-use testing will be produced at limited times during the demonstration period by using only the first distillation column.

Catalyst slurry is activated in the catalyst reduction vessel, which is equipped with a heating/cooling jacket, utility oil skid, and agitator. Pure CO, diluted in nitrogen, acts as the reducing agent. During the activation procedure, slurry temperature is carefully increased while monitoring consumption of CO to determine when the catalyst is completely reduced. At the end of this procedure, the catalyst is fully active and can be pumped directly to the reactor. Catalyst inventory is maintained by a combination of catalyst addition and withdrawal: as fresh catalyst slurry is added to the LPMEOH™ reactor, catalyst inventory is maintained by withdrawing an equivalent amount of partially deactivated or spent slurry.

Initial Operation

Table 2 summarizes the commissioning and startup milestones at the LPMEOH™ Demonstration Plant.

Table 2.

LPMEOH™ Demonstration Plant Milestones

• Groundbreaking	October 1995
• Plant Mechanically Complete	January 1997
• Eastman Begins Commissioning	February 1997
• Completed Startup	April 1997
• Achieved Design Catalyst Life	February 1998
• Achieved Design Catalyst Loading	September 1998
• Successful Reactor Inspection	March 1999
• Availability in 1998	99.7 %

After activation of nine 1-ton batches of methanol synthesis catalyst, the reduced catalyst slurry was pressure-transferred from a maintenance tank to the LPMEOH™ reactor on April 1, 1997. In less than two weeks of operation, the LPMEOH™ Demonstration Plant met several of its short-term performance goals. Methanol production reached the nameplate capacity of 260 TPD, and a stable test period at over 300 TPD of methanol revealed no system limitations, either in the reactor or distillation areas. The rapid progression from first introduction of syngas to stable operation at greater than nameplate capacity is an indication of the robust nature of the LPMEOH™ process. The startup also proceeded without injury or environmental incidents.

Since initial operation in April 1997 to the end of calendar year 1998, the LPMEOH™ Demonstration Plant achieved an availability in excess of 96%. During the first year of operation, a 31-day continuous run was achieved which helped to illustrate and confirm the overall system reliability. The H₂/CO ratio in the reactor feed stream was varied from 0.4 to 5.6 with no negative effects on performance. The results pertaining to gas holdup (the volume fraction of the reactor occupied by gas), an important design parameter for slurry reactors, have provided initial confirmation of the equipment scale-up parameters for the LPMEOH™ reactor. Important parameters such as high inlet superficial velocity of reactor feed gas, maximum expanded slurry level, and the overall heat transfer coefficient of the internal heat exchanger have been demonstrated at 115 - 120% of design levels.

Initial catalyst life data indicated an accelerated change in performance occurred; whereas, the remaining operation from June 1997 through November 1997 matched the typical activity loss measured in the laboratory. Figure 4 shows performance results from the LPMEOH™ reactor during the first several months of operation. The data are reduced to a ratio of rate constant pre-exponential factors (actual vs. design value for fresh catalyst), using an in-house kinetic model, to eliminate the effects of changing feed composition or operating conditions. Typical

exponential decay will appear as a straight line on a log-plot, as shown. The curve fit to data from a 4-month test at the LaPorte PDU in 1988/89 and laboratory autoclave data from 1996 are included for reference.

An important feature of the LPMEOH™ Process is the ability to remove spent catalyst from the reactor during operation; this also affords the opportunity to examine samples for changes in the microscopic structure and/or chemical make-up of the catalyst with time. Analyses of early samples from Kingsport have indicated a step-change increase in the concentration of iron on the catalyst surface during the initial six weeks which cannot be correlated to the presence of iron carbonyl in the feed gas streams. This finding is most likely related to the detection of post-construction debris within various parts of the facility. Higher than expected levels of arsenic were also found on the catalyst samples. After an initial operating period of seven months, the reactor was drained and another partial charge of fresh catalyst was activated during December of 1997.

Kingsport LPMEOH™ Catalyst Life (First Campaign: 1997)

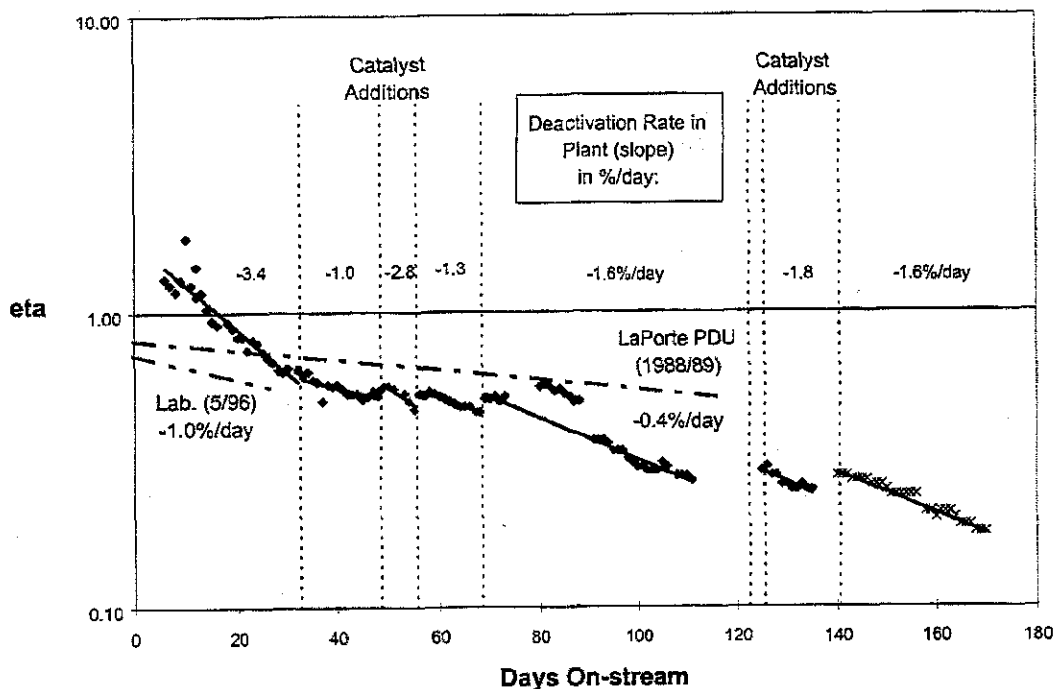


Figure 4
Catalyst Life During Campaign 1

Performance Results - December 1997 to December 1998

Catalyst life was exceedingly improved during the second campaign of operation which began in December 1997. Iron levels in the catalyst samples did not increase significantly during this operating period. This further supports the conclusion that early elevated iron levels were a function of construction debris or start-up conditions. During this second operating campaign, the reactor temperature was lowered to 235°C, a reduction from the 250°C temperature used during initial operation. This was an effort to further investigate catalyst performance issues. The calculated catalyst activity curve since the restart is included in Figure 5. The combined results of lowered reactor temperature and reduced poison deposition were a catalyst life or deactivation rate that met or exceeded the life achieved in the LaPorte PDU during several long duration operation periods. A parallel lab test trial conducted on plant gas is shown for comparative purposes.

Kingsport LPMEOH™ Catalyst Life (Second Campaign: 1997-1999)

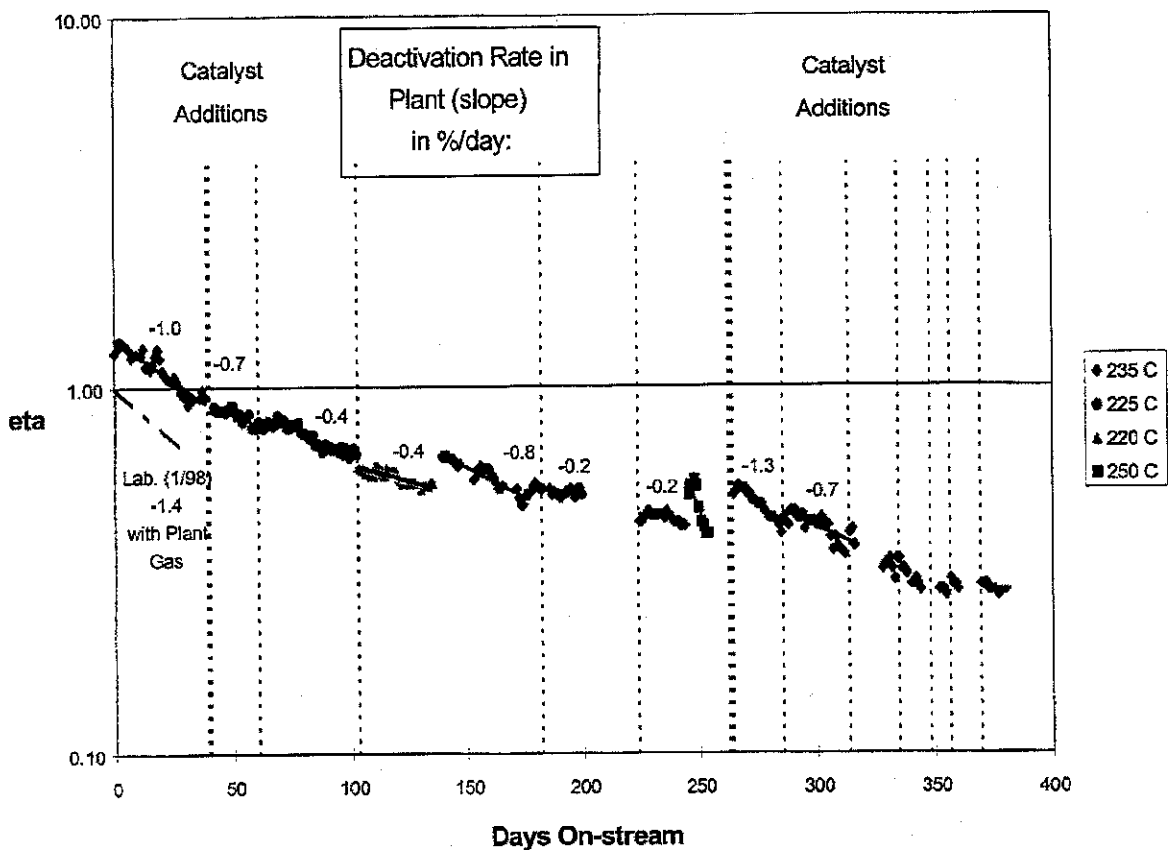


Figure 5
Catalyst Life During Campaign 2

Although the presence of iron on the catalyst samples was not significant during this second theater of operations, levels of arsenic and, to a lesser degree, sulfur increased noticeably. The arsenic and sulfur compounds are potential catalyst poisons found in the coal-derived syngas. However, there is no definitive correlation linking either species to catalyst deactivation results. To further mitigate the effects of arsenic on the catalyst, arsenic removal capacity will be increased in guard beds located both upstream and within the LPMEOH™ Process. The level of all potential poisons will continue to be monitored during the on-going plant operation.

A major area of consideration has been to study the effect of higher catalyst loading on reactor performance. During the latter part of 1998, a concerted effort was made to increase the catalyst loading and slurry concentration through judicious additions of catalyst batches. Figure 6 shows the concentration of the reactor slurry during this second campaign of operation. As shown in the figure, the design catalyst concentration of 40% was significantly exceeded with values as high as 49% experienced. In addition, a catalyst inventory loading of over 150% of design was achieved in the reactor during this period of operation. No negative effects, including mass transfer limitations, were experienced during this operating period.

A key design feature of the slurry reactor is its ability to manage the heat release from exothermic reactions such as methanol synthesis. Since startup, the heat management performance of the LPMEOH™ reactor has been outstanding. In fact, the temperature difference between the process and the steam system is essentially constant along the length of the reactor. The maximum temperature profile in the slurry, as measured by 35 thermocouples at various axial and radial intervals, is 3 to 4°C axially, and less than 1°C radially. The heat transfer coefficient for the internal heat exchanger has exceeded the design value and has indicated little fouling to date. The absence of slurry-side fouling has been additionally confirmed by inspection of the heat exchanger during a scheduled outage.

Kingsport LPMEOH™ Slurry Concentration (Second Campaign: 1997-1999)

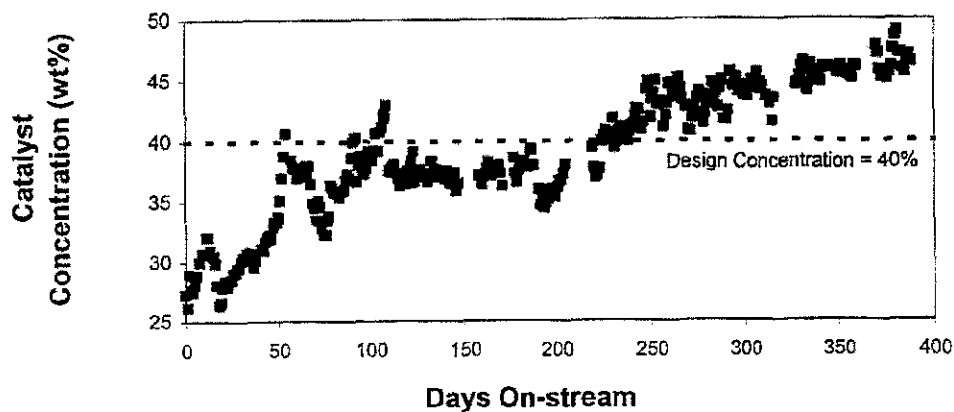


Figure 6
Catalyst Slurry Concentration During Campaign 2

Gas holdup, the volume fraction of the reactor occupied by gas, is an important parameter for sizing a LPMEOH™ reactor. A low holdup may indicate poor mixing, likely resulting in sub-optimum reactor performance. A high gas holdup leaves less space in the reactor for catalyst inventory. Pressure-differential transmitters, at regular intervals along the length of the reactor, measure the average density in discrete volumes of slurry. The gas holdup is calculated for each section using the known catalyst loading and the physical properties of the three phases. The results pertaining to gas holdup and heat management have provided initial confirmation of the equipment scale-up parameters for the LPMEOH™ reactor; additional operating time will verify long-term performance and the impact of changes in other operating conditions, such as gas composition and flowrate.

The LPMEOH™ Demonstration Plant was shutdown in early March 1999 to begin a scheduled bi-annual inspection of all pressure vessels as required by Tennessee state code. Catalyst slurry was pressure transferred from the LPMEOH™ reactor to the slurry holding tank and contained during the outage period. No issues were observed with any of the units evaluated as part of the code inspection. The walls and internal heat exchanger of the LPMEOH™ reactor internally showed no evidence of erosion, pitting, or fouling by catalyst slurry. The inspection activities were completed in a timely manner and the catalyst slurry was transferred back from the slurry holding tank to the LPMEOH™ reactor on 13 March 1999 for a restart of operation. Following the inspections, the LPMEOH™ Demonstration Plant was re-started on 14 March 1999 with the transferred catalyst inventory.

A scheduled complex-wide outage followed in mid-April at the Eastman Chemical facility as the LPMEOH™ Demonstration Plant passed into its third year of operation. During this outage, the LPMEOH™ Demonstration Plant was held with a full catalyst load under stand-by conditions for over 11 days. The successful re-start after this outage further speaks to the robustness of the technology to handle start-up, shutdown, and stand-by conditions.

Future Activities

During 1999, efforts will continue to sample the catalyst from the reactor and monitor plant performance to quantify the long-term catalyst aging characteristics under coal-derived syngas. In addition, operations with CO-rich syngas and other reactor feed gas compositions are planned.

V. CONCLUSION

The LPMEOH™ Process is now being demonstrated at commercial scale under the DOE Clean Coal Technology Program. The demonstration plant, located at Eastman Chemical Company's Kingsport, Tennessee coal gasification facility, has produced in excess of the 260 TPD of methanol nameplate capacity from coal-derived syngas. Since startup of the unit in April of 1997, overall availability has exceeded 96 %, while the more recent campaign in calendar year 1998 achieved 99.7 % availability. The startup and initial operation proceeded without injury or

environmental incidents, and Eastman has accepted all of the greater than 35 million gallons of methanol produced at the LPMEOH™ Demonstration Plant for use in downstream chemical processes.

Successful demonstration of the LPMEOH™ technology will add significant flexibility and dispatch benefits to IGCC electric power plants, which traditionally have been viewed as strictly a baseload power generation technology. Now, central clean coal technology processing plants, making coproducts of electricity and methanol, can meet the needs of local communities for dispersed power and transportation fuel. The LPMEOH™ Process provides competitive methanol economics at small methanol plant sizes, and a freight and cost advantage in local markets vis-à-vis large offshore remote gas methanol. Methanol coproduction studies show that methanol can be produced at economically competitive levels from an abundant, non-inflationary local fuel source, such as coal. The coproduced methanol may be an economical hydrogen source for small fuel cells, and an environmentally advantaged fuel for dispersed electric power.

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