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DIRECT CONVERSION OF LIGHT HYDROCARBON
GASES TO LIQUID FUEL

DOE/PC/89866--T2

Report No. 8

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for
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For

U. S. Department of Energy
Pittsburgh Energy Technology Center
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By

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TECHNICAL STATUS

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EXECUTIVE SUMMARY

Amoco Oil Company, under a contract with the United States Department of Energy, is investigating the direct conversion of light hydrocarbon gases to liquid fuels via partial oxidation. This report describes work completed in the second quarter of the two-year project. Task 1 of the work, preparation of the Project Management Plan, was completed in the first quarter. Work continued and progress was made on three other tasks during this quarter:

Task 2. Modification of an existing Amoco pilot plant to handle the conditions of this project. Detailed design of a new reactor for Task 3.5 (effect of reactor geometry) has been completed and materials ordered. A compressor system for the oxygen feed line has been designed and vendor bids are being received. An oxygen compressor will facilitate operation of the plant for extended periods at high pressures.

Task 3.1. Evaluation of the suitability of the Los Alamos National Laboratory kinetic model in guiding the experimental portions of this project. A proposal was made to postpone work on this task. This was done because the Los Alamos model was written and tuned for pure methane feeds, whereas our plant data show that higher hydrocarbons should be included in the feed to more accurately evaluate a potentially commercial process. It is questionable whether the Los Alamos model can provide us with useful information for our system.

Task 3.2. Process variable (e.g. temperature, pressure, residence time) studies to determine optimal partial oxidation conditions. Twenty runs were made on the pilot plant to study the effects of higher hydrocarbons, temperature, pressure, and residence time on methanol production. The presence of higher hydrocarbons (ethane and propane) increased methanol yield but decreased methane conversion. The pressure and temperature effects are quite complex. In general higher pressures are beneficial for increased methanol production. At higher pressures (1300 psig), lower temperatures appear to be desirable, though this trend is reversed at lower pressure (1100 psig). The highest methanol yield observed to date was 6.6% at 800°F, 1300 psig and 20 seconds residence time.

The project continues to proceed on schedule. Work in the next quarter will extend the process variable studies to lower temperatures and shorter residence times. The effect of oxygen and ethane concentration will also be studied. The new reactor will be installed in the next quarter and operated to determine reactor geometry effects.

BACKGROUND

Fischer-Tropsch synthesis, gasification processes like Lurgi dry bottom gas, direct coal liquefaction, and remote natural gas all represent sources of substantial quantities of light hydrocarbon gases. Methane is the major and most stable component of all these gases. Steam reforming methane to produce synthesis gas is capital-intensive because it is highly endothermic and requires severe reaction conditions. A process for direct conversion of light gases, especially methane, to methanol, gasoline, or other liquid fuels could be far superior.

Steam reforming is the first stage in traditional commercial methods for the production of liquid fuels. This first step produces synthesis gas:

The synthesis gas is then converted into methanol via a catalytic process.

Reaction 1 produces more hydrogen than required by reaction 2. The excess can either be utilized elsewhere in the case of a domestic refinery or, in the case of a remote operation, is lost. A third step could be the catalytic condensation of methanol to gasoline.

A more efficient route of converting light hydrocarbons would be to directly form methanol by partial oxidation.

Such a process could substantially reduce capital and energy requirements for methanol production. The methanol could be used as a fuel or a fuel blending component, as in the case of M80 fuels (80% methanol, 20% gasoline), or else converted into gasoline through well-known processes, such as MTG. A plant based on Reactions 1 and 2 followed by methanol condensation to gasoline has been built and is operating in New Zealand. However, the process is uneconomical if it were not for New Zealand Government support. If a process for the direct conversion of light hydrocarbons to methanol is feasible, thereby eliminating the process steps shown by Reactions 1 and 2, then a gas-to-gasoline process could become economically viable.

A proposed process for converting light hydrocarbon gases directly to hydrocarbon liquids, e.g., methanol or formaldehyde, is not new. In 1932 Newitt and Haffner reported the formation of methanol, along with smaller amounts of formaldehyde and formic acid, in the high-pressure oxidation of methane.⁽¹⁾ The reaction was carried out in a static system at 360-393°C and 50-150 atm. The maximum methanol selectivity was ca. 22%; however, CH₄ conversion only amounted to a few percent. More recently, Gesser, Hunter and co-workers have reported methanol selectivities up to 89% and yields of around 7%.⁽²⁾ However, recent attempts to reproduce these results have not proved successful.⁽³⁾

- (1) D. M. Newitt, A. E. Haffner, Proc. R. Soc. London, 1932, Ser. A, 134, p. 591.
- (2) H. D. Gesser, N. R. Hunter, Chem. Rev., 1985, 85(4), p. 235,
H. D. Gesser, U. S. Patent 4,618,732, issued 10/21/86.
- (3) R. Burch, G. D. Squire and S. C. Tsang, J. Chem. Soc. Faraday Trans. 1, 1989, 85 (10), 3561-3568.

PROGRAM OBJECTIVES

The objective of this program is to investigate the direct conversion of light gaseous hydrocarbons, such as those produced during Fischer-Tropsch synthesis or as a product of gasification, to liquid transportation fuels via a partial oxidation process. The process will be tested in an existing pilot plant to obtain credible mass balances. Specific objectives to be met include determination of optimal process conditions, investigation of various processing options (e.g. feed injection, product quench, and recycle systems), and evaluation of an enhanced yield thermal/catalytic system. Economic evaluation of the various options will be performed as experimental data become available.

PROJECT DESCRIPTION

The project is of two years' duration and contains three major tasks. The third task (Pilot Plant Experiments) contains seven subtasks, corresponding to the project objectives outlined above. The tasks and subtasks foreseen when the project began are described below.

Task 1.--Project Management Plan: A plan will be prepared describing the work to be done, milestones, and manpower requirements and costs.

Task 2.--Pilot Plant Modification: An existing pilot plant dedicated to investigation of light hydrocarbon conversion will be modified to provide it with the capability to handle the processes and conditions of this program. These modifications will include construction of a new reactor, construction and installation of reactant injection and product quench systems, and, possibly, addition of a product recycle loop to the unit.

Task 3.1.--Comparison of Preliminary Data With Los Alamos Model: We will determine if the kinetic model developed by Los Alamos National Laboratory can be used to guide our experimental effort. Results from this task will be carefully analyzed and will determine the direction of the subsequent experimental program. This is a major decision point in the project.

Task 3.2.--Pressure/Temperature/Reaction Time Effects: The methane conversion data base will be extended over the following range of conditions:

Temperature:	600 to 1100°F
Pressure:	200 to 1300 psig
Reaction Time:	3 to 90 seconds

These experiments will be guided by the results of Task 3.1 to those process regimes which appear most promising.

Task 3.3.--Study of Different Injection Systems: Different schemes for introducing and mixing reactants before or within the reactor will be evaluated theoretically and/or experimentally. The goal will be to maximize methanol yield.

Task 3.4.--Study of Different Quench Systems: The efficacy of different product cooling techniques will be investigated to determine the effect of quenching on product composition and methanol yield. Both gas and liquid quench options will be investigated.

Task 3.5.--Effect of Reactor Geometry: The effect of reactor geometry, particularly aspect (i.e. length/diameter) ratio, will be investigated to determine mass transfer and mixing effects on product composition and methanol yield.

Task 3.6.--Effect of Reactor Recycle: The effect of recycling unreacted hydrocarbons to the reactor inlet will be evaluated first by appropriately blending the feed stream to simulate reactor recycle. If these results are promising relative to methanol production, a recycle compressor and recycle line will be added to the pilot plant for more detailed tests.

Task 3.7.--Enhanced-Yield Catalyst Study: An attempt will be made to develop a combined thermal/catalytic process in which byproduct carbon monoxide and hydrogen from the thermal process are converted to methanol over a heterogeneous catalyst. Such a combined process may provide higher methanol yields than the thermal process alone.

Reporting will be done periodically throughout the duration of the project according to DOE guidelines.

RESULTS AND DISCUSSION

During this quarter, pilot plant runs (Task 3.2) demonstrated significant differences between pure methane and natural gas feeds, and probed the effects of temperature, pressure, and residence time on methanol yield and selectivity. Based on these pilot plant runs, a proposal was made to postpone further work with Los Alamos' kinetic model (Task 3.1), since it was written and tuned for pure methane feeds. Pilot plant modifications (Task 2) progressed to detailed design of a new reactor and solicitation of bids for an oxygen compressor.

Task 2: Pilot Plant Modification

Two modification projects were underway during the reporting period: design of a compressor system for the oxygen feed line, and design of a new reactor for the reactor geometry studies (Task 3.5; scheduled to begin in June 1990). Installation of a compressor in the oxygen feed line is desirable if many runs will be made at high pressure (>1000 psig). This results because full oxygen cylinders are delivered at 2300 psig, and (without a compressor) can only provide oxygen flow when above the operating pressure of the plant. Therefore, if the plant is operating at high pressure, only a fraction of the oxygen in the cylinder can be used. Since the process variable studies have shown high pressures to be beneficial for methanol production (see below), design of a compressor system was initiated. Meetings were held with site safety personnel and vendor compressor designs were evaluated. Two compressor configurations are available: single and triple diaphragm. The single diaphragm compressors are simpler and less expensive, but require fluorinated hydraulic oils rated for oxygen service. Triple diaphragm compressors require no special oil, but are significantly more expensive. Vendor bids are currently being received and a compressor will be selected based on safety, reliability, and cost.

Construction drawings for the new reactor (for Task 3.5) have been completed, and materials ordered. This new reactor will have a larger diameter (smaller length/diameter ratio) than the current reactor. The larger internal diameter also makes the reactor suitable for service with the various feed injection/product quench options (Tasks 3.3 and 3.4).

Task 3.2: Process Variable Studies:

A total of 20 well mass-balanced runs were made in this quarter to study the effects of temperature, pressure, residence time and feed composition on methanol yield. The results of these runs are presented in Tables I-IV below and graphically in Figures 1 - 12. Unless otherwise noted, the hydrocarbon/oxygen was 10/1 and the residence time of reactants in the reactor was 35 seconds.

Reproducibility of the Data

Three replicate runs were completed at two different sets of conditions to provide insight into the reproducibility of the pilot plant data. These results are shown in Table I. Both raw and "adjusted" data are presented. The "adjusted" data results from the application of a statistical adjustment algorithm to the raw data. This algorithm achieves perfect mass and element balances by adjusting all process variables within their respective error limits.

Table I
Replicate Runs; Check for Reproducibility
Natural Gas Feed; Res. Time = 35 sec.; HC/O₂ = 10

Run No.	Mass Balance (%)	Unadjusted Data			Adjusted Data		
		CH ₄ Conv.	MeOH Sel.	MeOH Yield	CH ₄ Conv.	MeOH Sel.	MeOH Yield
Temperature = 800°F; Pressure = 1300 psig							
28.003	-1.3	5.6	25.9	4.3	4.9	35.6	6.0
31.001	-2.4	8.1	23.5	4.7	4.7	33.7	5.6
31.009	-1.7	7.8	28.2	5.4	4.5	33.6	5.4
Ave.		7.2	25.9	4.8	4.7	34.3	5.7
Std Dev		1.4	2.4	0.6	0.2	1.1	0.3
Temperature = 850°F; Pressure = 1100 psig							
27.006	-2.5	6.6	25.6	4.7	4.0	33.0	5.5
28.001	2.0	2.8	24.0	3.1	3.0	31.5	5.0
28.010	-1.5	5.1	25.1	4.2	4.9	32.9	5.7
Ave.		4.8	24.9	4.0	4.0	32.5	5.4
Std Dev		1.9	0.8	0.8	1.0	0.8	0.4

HC = Total hydrocarbons

Several conclusions can be drawn from these data. First, the adjusted data are much more reproducible than the unadjusted data, as evidenced by the lower standard deviation values. Second, the adjusted data show good reproducibility (the standard deviation is generally within 3-8% of the average). However, the standard deviation for the CH₄ conversion at 850°F and 1100 psig was 25% of the average. This may be due to the small conversions and relatively large total flows that exist in this system. Calculations are based on small differences between large numbers, so the experimental errors are relatively large. Third, the adjustment routine makes significant changes to the calculated values, particularly the methanol selectivity values. This again is a result of the measurement difficulties present when operating at low conversions. If the adjustments are not made, however, the differences in overall mass balances, small though they are, tend to mask any process-related differences. We therefore will report only the adjusted data in the remainder of this report, feeling that this provides a more consistent basis on which to compare different conditions.

Effect of Feed Composition (Higher Hydrocarbons)

Table II shows the effect of higher hydrocarbons (ethane and propane) on hydrocarbon conversion and product selectivity. Pure methane and natural gas feeds were used and comparisons made at a number of temperatures and pressures. The natural gas contained about 89% methane, 5% ethane, 1% propane, 1% C₄+, 3% nitrogen, and 1% carbon dioxide. The major impurity in the "pure" methane was ethane at 0.25%. The effect of feed type on methanol yield, methanol selectivity, and methane conversion are shown in Figures 1, 2 and 3, respectively. In all cases the residence time was near 35 seconds, and hydrocarbon/oxygen was 10/1.

Table II
Comparison of Natural Gas and Pure Methane Feeds
for Partial Oxidation to Methanol
Meth. = Pure Methane Feed; N.G. = Natural Gas Feed

Press. (psig)	Temp. (F)	Hydrocarbon Conversion (percent)		Methane Conversion (percent)		Methanol Selectivity (percent)		Methanol Yield (percent)	
		Meth.	N.G.	Meth.	N.G.	Meth.	N.G.	Meth.	N.G.
350	850	7.7	16.0	7.1	3.1	28.9	30.7	2.2	4.9
825	850	8.7	16.7	8.0	3.7	32.3	32.5	2.8	5.4
1100	850	8.6	16.8	7.8	4.0	36.1	33.0	3.1	5.5
1100	990	8.9	17.2	8.2	4.7	34.2	33.1	3.0	5.7
1300	800	9.3	16.7	9.3	4.9	37.1	35.6	3.5	6.0
1300	850	9.1	17.2	8.4	3.0	37.3	30.7	3.4	5.3
1300	990	8.7	16.2	8.1	2.2	33.9	26.8	3.0	4.3

These data show a number of significant trends. It is apparent that methanol yields are significantly higher with natural gas feeds than with pure methane. This increase in methanol yield is primarily due to increased hydrocarbon conversion. Methanol selectivity is slightly higher with pure methane feeds, but methane conversion with natural gas feeds is only about half the 7-9% observed in the pure methane runs. This can be attributed to limited oxygen availability in these experiments. The easier to react higher carbon number hydrocarbons in the natural gas consume much of the oxygen, leaving little to combine with the less-reactive methane.

Figure 1
Effect of Feed Type on Methanol Yield
Natural Gas Compared to Pure Methane Feed

Figure 2
Effect of Feed Type on Methanol Selectivity
Natural Gas Compared to Pure Methane Feed

Figure 3

**Effect of Feed Type on Methane Conversion
Natural Gas Compared to Pure Methane Feed**

Figure 4

**Effect of Pressure on Methanol Yield
Natural Gas Feed; Carbon-Based Yield**

Pressure and Temperature Effects

Table III presents the effect of pressure and temperature on conversions and selectivities. The effects of pressure on methanol yield, methane conversion and methanol selectivity are shown in Figures 4, 5 and 6, respectively. The effects of temperature on these parameters are shown in Figures 7-9. The composition of the natural gas feed was identical to that given in the previous section.

Table III
The Effect of Pressure and Temperature on Conversions and Selectivities
Based on moles of carbon converted

Press. (psig)	Methane Conv. (%)	HC Conv. (%)	Selectivity (%)*			MeOH Yield (%)	Initial Balance Closure (%)
			MeOH	CO	CO ₂		
Temperature = 800°F							
1100	2.5	16.6	31.4	46.7	19.7	5.2	1.6
1300	4.9	16.7	35.6	42.3	19.4	6.0	-1.3
Temperature = 850°F							
350	3.1	16.0	30.7	50.4	17.8	4.9	-0.7
825	3.4	16.9	30.5	48.9	18.6	5.2	-0.7
1100	4.0	16.8	33.0	44.2	20.0	5.5	-2.5
1300	3.0	17.2	30.7	47.1	20.2	5.3	4.3
Temperature = 990°F							
1100	4.7	17.2	33.1	45.9	18.4	5.7	-1.8
1300	2.2	16.2	26.8	48.7	23.3	4.3	0.1

HC = Hydrocarbon

* Remainder is formaldehyde and higher alcohols

The effects of temperature and pressure on conversions and selectivities are rather complex. At a temperature of 850°F methanol yield, methanol selectivity, and methane conversion all increase with increasing pressure up to 1100 psi. Above 1100 psi the trend appears to reverse, in agreement with higher-temperature (990°F) data. However, 800°F data in the 1100-1300 psi range show the same trends as the 850°F data did in the 350-1100 psi range. Correspondingly, the effect of temperature on the reaction parameters appears to depend on the pressure (Figures 7-9).

Figure 5
Effect of Pressure on Methane Conversion
Natural Gas Feed

Figure 6
Effect of Pressure on Methanol Selectivity
Natural Gas Feed; Carbon-Based Selectivity

Figure 7

**Effect of Temperature on Methanol Yield
Natural Gas Feed; Carbon-Based Yield**

Figure 8

**Effect of Temperature on Methane Conversion
Natural Gas Feed**

Figure 9

Effect of Temperature on Methanol Selectivity
Natural Gas Feed; Carbon-Based Selectivity

Figure 10

Effect of Res. Time on MeOH Yield and CH₄ Conv.
Natural Gas Feed; HC/O₂=10; P=1300 psig; T=800 F

At high pressure (1300 psig) lower temperatures are apparently preferable; while at a lower pressure (1100 psig) the trend is reversed, as higher temperatures appear to be desirable. The highest methanol yield (6.0%) and methane conversion (4.9%) occur at the lowest temperature and highest pressure studied: 800°F and 1300 psig.

Some of the apparent complexity of the temperature/pressure effects may be due to the nature of the experimental data obtained. With such small conversions and large total flows, experimental variations between runs are significant, even with statistical adjustment of the data (see previous section). For example, the trend of increased methanol production with increased temperature at 1100 psig (Figures 7-9) is not statistically significant (at 85% confidence level) given the standard deviations in Table I. Replicates of these runs are needed to certify the validity of this trend.

The literature on this system is quite fragmented and often contradictory, making comparisons difficult. Few publications deal with conditions within the range studied here. Those that cover temperatures and/or pressures in the range studied here include Burch et al.¹, Garcia and Loeffler², the work of Gesser et al.^{3,4} & references therein, and Wiezevich and Frolich⁵. However, all of these studies except Wiezevich and Frolich used pure methane feeds, while we used natural gas. There is also a body of Russian work on this system, and we are having some of the key articles translated.

The majority of the publications cited above assert that selectivity to methanol increases with increasing pressure²⁻⁵. Our 850°F and 800°F data agree with this, but our 990°F data show the opposite trend. The data of Burch et al. also show a temperature dependence on the pressure trend, but it is the opposite of ours. Their data show that increased pressure increases methanol selectivity at high temperatures (above 880°F), but decreases methanol selectivity at low temperatures (below about 800°F). Burch et al. used pure methane feeds at lower pressures (up to 735 psig). Such contradictions in the literature may be due to the large experimental errors encountered, and the high system-to-system variability that seems to exist¹.

Our temperature trend at high pressure (e.g. increased selectivity to methanol at lower temperatures) agrees with the majority of the literature^{1,3,5}. In this work we have not been able to reproduce the high selectivities reported by Gesser et al.^{3,4}. Our methanol selectivities are in the 30-35% range, consistent with other published reports^{1,5}, but significantly lower than Gesser et al.'s 89%. It is possible that the methanol selectivity is highly dependent on the design of the reactor or on special quenching of the hot product gases.

Residence Time Effects

Residence time effects were also studied. Table IV presents data on the effect of residence time on conversions and selectivities for this system. The trends in methanol yield and methane conversion are shown graphically in Figure 10, and the trends in hydrocarbon conversion and product selectivity are shown in Figures 11 and 12, respectively. In these runs the temperature was 800°F, the pressure was 1300 psig, and the feed was natural gas.

Figure 11

Effect of Res. Time on Hydrocarbon Conversion
Natural Gas Feed; HC/O₂=10; P=1300 psig; T=800 F

Hydrocarbon Conversion (%)

Figure 12

Effect of Res. Time on Product Selectivity
Natural Gas Feed; HC/O₂=10; P=1300 psig; T=800 F

Carbon-Based Selectivity (%)

Table IV
Effect of Residence Time on Conversions and Selectivities
Based on moles of carbon converted

Res. Time (sec)	Methane Conv. (%)	HC Conv. (%)	Selectivity (%) [*]			MeOH Yield (%)	Initial Balance Closure (%)
			MeOH	CO	CO ₂		
93	1.5	15.9	26.7	47.8	23.7	4.2	9.0
64	5.1	17.3	34.2	41.2	19.4	5.9	-1.3
36	4.9	16.7	35.6	42.3	19.4	6.0	-1.3
21	5.7	17.8	37.1	41.6	17.1	6.6	-2.3

HC = Hydrocarbon

^{*} Remainder is formaldehyde and higher alcohols

These data indicate that carbon-based methanol yields and selectivities increase with decreasing residence times at these conditions. The Los Alamos kinetic model also predicts that short residence times are desirable for methanol production. The selectivity trend is in agreement with that reported at similar temperatures by Burch et al.¹, but their yield trend is the reverse of ours. However, they operated at lower pressure (735 psig) and used a pure methane feed. The fact that only the yield trends show differences means that their hydrocarbon conversion decreased at lower residence time, while the above data show the reverse. The discrepancy in yield trend with residence time could be due to the conditions employed, a reactor design effect, or even a difference between pure methane and natural gas feeds.

- ¹ R. Burch, G. D. Squire and S. C. Tsang, J. Chem. Soc., Faraday Trans. 1, 1989, 85(10), 3561-3568.
- ² E. Y. Garcia and D. G. Loeffler, Lat. Am. J. Chem. Eng. Appl. Chem., 1984, 14, 267-284.
- ³ P. S. Yarlagadda, L. A. Morton, N. R. Hunter and H. D. Gesser, Ind. Eng. Chem. Res., 1988, 27, 252-256.
- ⁴ H. D. Gesser, N. R. Hunter and C. B. Prakash, Chemical Reviews, 1985, 85(4), 235-244.
- ⁵ P. J. Wiezevich and P. K. Frolich, Ind. & Eng. Chem., 1934, 26(3), 267-276.

CONCLUSIONS

The data trends comparing natural gas and pure methane feeds are quite clear and consistent. They indicate that the presence of higher hydrocarbons (mostly ethane and propane) has a pronounced effect on this partial oxidation system. Of special significance are the observations that natural gas feeds give higher methanol yields, but lower methane conversions. The increase in methanol yield stems from the increased hydrocarbon conversion; the higher hydrocarbons are more easily reacted than methane. The decrease in methane conversion with natural gas feeds is also due to the presence of higher hydrocarbons. Since the system is oxygen-limited (hydrocarbon/oxygen is 10/1), the more readily reacted higher hydrocarbons consume most of the available oxygen, leaving less to react with methane.

These results show that it is very important to run process variable studies with a feed representative of a commercial operation. The economics of a commercial partial oxidation process are closely tied to both methanol selectivity and methane conversion. The above data confirm that methane conversion is significantly affected by the presence of higher hydrocarbons. We have chosen, therefore, to run all future tests using natural gas feeds in order to more closely simulate commercial operation. We also proposed postponing work with the Los Alamos kinetic model (Task 3.1), since it was written and tuned for pure methane feeds. We feel that the resources of the project could best be used (at least initially) by making actual plant runs.

The effects of temperature and pressure on methanol yield and methane conversion appear to be quite complex. The majority of our data (and data reported in the literature) suggest that higher pressures are beneficial for methanol production. Trends with temperature seem to depend on the pressure of the system. At higher pressures (1300 psig), operation at lower temperature produces more methanol. At slightly lower pressure (1100 psig), short residence times also appear to be beneficial for methanol production. The highest methanol yield observed so far (6.6%) occurred at the lowest temperature (800°F), highest pressure (1300 psig) and shortest residence time (20 seconds) studied. Since we have not been able to reproduce the high selectivity reproduced by Gesser et al, we will study the Gesser work and consider his findings before proceeding with our quench studies. Hopefully, results from our reactor geometry study (Task 3.5) and product quench tests (Task 3.4) will shed more light on the selectivity issue.

FUTURE WORK

The project continues to proceed on schedule. In the upcoming quarter we plan to continue our process variable studies (Task 3.2). We will test the effect of lower temperatures (to 600°F) and lower residence times (down to 3 seconds). We cannot study higher pressures, since 1300 psig is at the limit of our operating range. The effect of hydrocarbon/oxygen will be studied in a series of runs, as will the effect of varying levels of ethane in a methane feed. These tests should more clearly determine optimum operating conditions for methanol production.

These optimum conditions will then be used as base conditions for testing the effect of reactor geometry on methanol production. A new, larger diameter reactor will be installed on the unit. Then, some process variable studies will be performed with this new reactor to test for possible reactor design/process variable interactions.

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