

CATALYTIC MULTI-STAGE LIQUEFACTION OF COAL AT HTI
Bench-Scale Studies in Coal/Waste Plastics Coprocessing

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INTRODUCTION

The development of Catalytic Multi-Stage Liquefaction (CMSL) at HTI has focused on both bituminous and sub-bituminous coals using laboratory, bench and PDU scale operations. The crude oil equivalent cost of liquid fuels from coal has been curtailed to about \$30 per barrel, thus achieving over 30% reduction in the price that was evaluated for the liquefaction technologies demonstrated in the late seventies and early eighties. Contrary to the common belief, the new generation of catalytic multistage coal liquefaction process is environmentally very benign and can produce clean, premium distillates with a very low (< 10 ppm) heteroatoms content. The HTI Staff has been involved over the years in process development and has made the following significant improvements in the CMSL processing of coals:

- Staging coal liquefaction reactions
- Lower temperature and higher residence times
- Heavier (343°C+) boiling recycle solvents preferred
- Low-High temperature mode of operation in catalytic processing
- Coal concentration in feed slurries increased from ca. 30 W% to ca. 53 W%
- Deep coal cleaning improved feedstock quality for liquefaction
- Continuous sulfating for low-rank, low-sulfur coals
- In-Line hydrotreating for product quality improvement
- Use of synthesis gas in first stage instead of pure H₂ improved net hydrogen utilization
- Interstage separation of light products (343°C-) with in-line hydrotreating improved process performance significantly
- Use of ashy recycle, containing unreacted coal, 343°C+ resid, and inerts, improved overall coal and resid conversion

A 24 month program (extended to September 30, 1995) to study novel concepts, using a continuous bench scale Catalytic Multi-Stage unit (30 kg coal/day), has been initiated since December, 1992. This program consists of ten bench-scale operations supported by Laboratory Studies, Modelling, Process Simulation and Economic Assessments. The Catalytic Multi-Stage Liquefaction is a continuation of the second generation of Catalytic Two-Stage Liquefaction approach, which results in high coal and resid conversions, and liquid yields using a low/high temperature approach. This paper covers work performed between October 1994 - August 1995, especially results obtained from the microautoclave support activities and the bench-scale operations for runs CMSL-08 and CMSL-09, during which, coal and the plastic components of municipal solid wastes (MSW) such as high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) were coprocessed.

Coal/Waste Plastics Coprocessing: Increasing problems associated with waste disposal have combined with the recognition that some raw materials exist in limited supply to dramatically increase interest in recycling. Recycling of paperboard, glass, and metal are technically straightforward and these materials are now commonly recycled in many areas around the world. Recycling of plastics presents greater technical challenges, primarily due to the differences in the chemical compositions/properties of various types of plastics. Some of the low-cost bulk plastics such as HDPE, PP, PS, and PVC find their way into advanced recycling/conversion processes that convert these plastics to petrochemicals further refinement of which could lead to isolation of monomers for plastics production or other high quality hydrocarbon products such as transportation fuels and lubricants. Used automobile tires, the main source of waste rubber, pose another environmental challenge. Most of the 200 million used tires that are discarded in the United States every

year, end up in stockpiles or landfills, although recently some use of these used tires are also reported in the power generation facilities. Other reported methods of recycling the scrap tires are based on pyrolysis which results in low thermal efficiency and also poor selectivity to liquid fuels.

Why process recyclable wastes such as plastics and used rubber tires together with coal? Well, coal is an abundantly available fossil fuel source with low hydrogen contents. The cost of hydrogen is a significant portion of the total cost of converting coal to refined transportation fuels such as gasoline, kerosene, and diesel via the state-of-the-art conversion technology. These municipal solid waste components such as plastics or hydrocarbon oil in used tires are relatively richer in hydrogen contents than coal. Thus, using these as a part of the feed in coal liquefaction would significantly reduce the cost of hydrogen production. There also seems to be a distinct advantage in processing plastics/rubber waste in a liquid phase or slurry mode under conditions much milder than those used in pyrolytic methods of conversion. Coal as a component of the feed mixture can thus provide not only a way to liquefy these waste stream, but can also act as a "mitigator" in maintaining the overall composition/properties of the combined feedstock more uniform. This mediator role of coal is very crucial for any waste-stream conversion/recycling process because the waste streams, depending on the location of the source, are going to inherently differ in their compositions. Thus, it appears to be practical to co-process the most abundantly available fossil fuel, coal, with hydrogen-rich, though in homogeneous in composition/properties, waste streams. The results obtained during the seven days of operation of the Proof-of-Concept Run No. 2 (POC-02) at HTI, using combined feeds of coal/plastics and coal/rubber, were very encouraging and established the technical as well as the operational feasibility of such combined processing. It also warranted further studies and process development efforts to optimize the coprocessing of coal with either waste plastics or used tire rubber to realize a commercially feasible plant operation.

OBJECTIVES

The overall objective of this 24 month Bench Scale study is to produce liquid fuels from direct coal liquefaction at a cost that is competitive with conventional fuels. This objective is to be accomplished with cumulative improvements through:

- Improvements in the effectiveness, use and to lower the costs of catalysts.
- Investigation of coal pretreatment and low temperature hydrogenation.
- Evaluation of hydrogen sources and improve hydrogen management to reduce the cost of liquid fuels to less than \$30/bbl.
- Improvements in the quality and acceptability of fuels from direct liquefaction, addressing concerns of 1990 Clean Air Amendment.
- Evaluation of coals of national interest and identify coals that have a good potential for easy liquefaction at mild conditions.
- Improvement in process energy efficiency and reduce carbon oxide emissions during processing.

- Screening of new concepts using continuous bench-scale units prior to the higher costs "Proof of Concept" demonstration.
- Providing input/feedback for the "Proof of Concept" demonstration program.
- Improvements in the overall process economics and environmental acceptability of coal conversion processes by utilizing low quality, cheap, and otherwise-hard-to-convert hydrocarbon feedstocks such as waste plastics, waste tire rubber, and heavy resids.

PROJECT STATUS

Microautoclave studies conducted during this reporting period include catalyst screening tests in supported of the bench operations CMSL-08 and CMSL-09. Additional tests were performed to evaluate the reactivity of different plastics, commonly found in municipal waste, and co-processing with coal under typical liquefaction conditions. The development of novel iron and molybdenum based dispersed catalysts, which can enhance the cracking of waste plastics.

A total of four bench scale operations, Runs CMSL-7 to 10, were carried out during this reporting period. The effect of lower pressure was evaluated in CMSL-07 replacing hydrogen by a mixture of syngas in the first stage of a two stage coal liquefaction operations. The co-liquefaction of coal and plastics was studied in Runs CMSL-8 and 9. In CMSL-8 a mixture of co-mingled plastics (or HDPE) was processed with Illinois No. 6 Coal from Crown II Mine in a Catalytic/Thermal configuration. Following Run CMSL-08, the combined processing of plastics with a sub-bituminous Wyoming coal (Black Thunder coal) was evaluated in a three stage configuration in Run CMSL-9. Both these runs involving waste plastics, varying from 25-50 W% of feed, were carried out under relatively high space velocities ranging from 480 to 640 Kg/h/M³ reactor volume. The last test of the CMSL program, Run CMSL-10, is in progress at the time this paper was prepared. The objective of CMSL-10 is to further evaluate the activity of iron and molybdenum based catalysts using Black Thunder coal (without any waste plastics) in a configuration similar to Run CMSL-9. The process performance of using Molyvan-A, a HTI iron based catalyst and a combination of these two catalysts will be compared in CMSL-10.

This paper discusses results obtained from Runs CMSL-8 and 9 only. Results from the other runs will be presented in the Contractors' review Meeting to be held in August.

ACCOMPLISHMENTS AND CONCLUSIONS

The following major accomplishments and conclusions can be drawn from work completed during this reporting period (October, 1994 to June, 1995):

1. In coal only operations, the conversion of coal was as high as 96% for Illinois No. 6 and Black Thunder coal. The corresponding C₄-524°C distillate yields of over 75% and 65% (maf basis) were obtained at relatively high space velocity.
2. Dispersed catalysts were found to be effective in improving the hydroconversion of coal and co-mingled plastics.
3. As compared with the coal only operations, co-liquefaction of coal and co-mingled plastics (20-50%) seemed to give as much as 15% more distillate of lighter quality, less C₁-C₃ gas make and lower hydrogen consumption.
4. Direct coupled in-line hydrotreating produced premium quality coal liquids containing 10-20 ppm of sulfur and as low as 10 ppm of nitrogen in processing both Illinois No.6 Crown II Mine and Wyoming Black Thunder Mine coals.

LABORATORY SCALE SUPPORT STUDIES

The laboratory scale support studies consisted of preparation and testing of different novel dispersed iron and molybdenum based catalysts for direct coal liquefaction and coal/plastics coprocessing. Microautoclave tests were also conducted to investigate the reactivity of various polymers that are found in MSW under typical coal liquefaction conditions. Studies were also carried out to determine the type of feed preparation section handling needed for plastics in the combined feed with coal. These also included a couple of off-line pumping tests for combined coal/plastics feeds, with 33 and 50 w% mixed plastics, to determine the effects of adding plastics to a coal/recycle solvent slurry in terms of its viscosity and other flow-related properties.

For CMSL-08, the laboratory support consisted of experiments, conducted in relation to the pre-reactor handling (mixing/dissolution and pumping) of the coal/solvent/plastic mixtures. In essence, two dissolution tests were conducted at 33 and 50 W% co-mingled plastics and remaining Illinois No. 6 Crown II mine coal (ca. 5 % moisture). The Tank-4 material, the oil used during the start-up and operations of the PDU Run POC-02, was used as solvent for dissolution. The Tank-4 material contained mostly petroleum-derived oils and small amounts of coal liquids obtained during POC-02. Thus, all compositions and ratios to be used during CMSL-08 were simulated in these tests. The approach used was to make, at room temperature, a slurry of coal and solvent, heating it to about 200-250°C and then adding co-mingled plastics to the slurry at that temperature. After allowing the plastics in slurry about 30-60 minutes at temperature, the hot mixture was observed to be fluid, homogeneous, and free of any lumps. Upon cooling down to room temperature, the mixture took an appearance of a plasticized and grainy filter cake material. This approach is certainly different from that employed successfully during the POC-02 run, although the new approach is less complicated as it will need only one pre-mix tank at high temperatures (200-220°C) instead of three (as during POC-02) and would also make the foaming problem due to moisture in coal more manageable. As a

result, this was the approach that was followed for the pre-reactor handling of the coal/plastics with recycle solvent during CMSL-08 bench run. The off-line pumping tests, carried out both at 33% and 50% plastics in the feed, using the hot slurry mix tank at 220°C, successfully demonstrated the pumpability of the feed mixtures.

The microautoclave tests using pre-dissolved/pre-mixed feed, carried out under conditions similar to those corresponding to the bench run, indicated as high as 92 W% maf conversion for coal+ plastics combined feed (@ 33% plastics) while the conversion was 90 W% maf (@ 50% plastics), both based on THF solubility of the products (Figure 1). These values were much higher than those obtained earlier (75-82 W% range) in the microautoclave tests that used the separately added coal and plastics feed. Thus, a distinct advantage is seen here in using the pre-dissolved/pre-mixed coal/plastics/solvent mixtures for the actual reaction studies. The reaction of HDPE and polystyrene (50/50 w/w%) mixture was carried out in the microautoclaves (20 cc) in the presence of dispersed acidic catalysts, HTI-I and HTI-II, at typical coal conversion process conditions. The results (Figure 2) indicate about 98-99 W% conversion of the plastics (which are mostly THF insoluble before reaction) into liquids (light, free flowing) and gases (C₁, C₅). Based on the difference in the reactor weights before and after reactions, the gas yields are estimated to be between 10-12 W% and the rest is light liquid (THF solubles). Further analysis of THF soluble products indicated that it was completely soluble in cyclohexane. This result seems to be very encouraging considering that the other laboratories working on the plastics hydrocracking/depolymerization have been using a strongly acidic and more expensive zeolites (HZSM-5 or Y-Zeolite) for this reaction. Both the catalyst additives, indicated above, have been developed in-house at HTI. In order to verify this result and also search for optimum conversion conditions, additional microautoclave tests were conducted under "coal liquefaction conditions".

Activity of molybdenum and iron based catalysts are also evaluated for coal dissolution. At similar Mo concentration, Molyvan-A seems to be slightly more active (5-7%) than Molyvan-L. The iron based catalyst, HTI-II, at higher concentration had a similar activity as the Molyvan-L, as shown in Figure 3.

Bench Scale Operations

The bench scale operations consisted of two continuous runs, CMSL-08 and CMSL-09, carried out in HTI's integrated unit 227, for a combined total of 64 days of operation on either coal-only or coal/plastics combined feed. The Bench Run CMSL-08 was a 22 day long operation to study the coprocessing of a bituminous Illinois No. 6 coal with 25-33 % mixed plastics consisting of 50% HDPE, 35% PS, and 15% PET. Bench Run CMSL-09 was a 40 day long operation, with last 12 days on a combined feed of coal and 33-50 w% plastics which consisted of about 40% HDPE, 33% PP, and 27% PS. The detailed run plans (operating conditions) for both CMSL-08 and CMSL-09 are summarized in Tables 4 and 5, respectively.

Bench Run CMSL-08

The bench-run CMSL-08 was successfully carried out for 22 continuous days spread over five conditions to investigate the effects of co-liquefying the primary plastic constituents of the municipal solid waste on the CMSL Process performance. This bench run was a follow-up of the earlier exploratory work Hydrocarbon Research, Inc. had carried out in the PDU scale continuous operations during the DOE sponsored POC-02 PDU run. During this bench run, the conditions were chosen to seek for the optimum set of operating severity/catalysis for converting plastics together with Illinois No. 6 coal. Although the work at the larger scale

demonstrated the operational and technical feasibility of the coprocessing of this type, the interpretation of the results was clouded by the fact that the continuous operation was never under solvent-balance, i.e., employed significant proportions of the external make-up oil as a part of the recycle stream for the process. A conscious effort was made to maintain the process under a net positive solvent-balance during the continuous bench operations CMSL-08, thereby minimizing any intrusive effects of an external make-up oil. The first stage reactor was provided with both the supported Ni-Mo/Alumina extrudate and the dispersed sulfated iron-molybdenum catalysts to ensure sufficient activity for the depolymerization of plastics in this stage while the second stage reactor was a back-mixed thermal reactor with no supported catalyst but with the dispersed catalyst, carried over from the first stage.

The overall process performance during the five work-up (Steady-State) periods of CMSL-08 is summarized in Figures 4 to 6. The first two run conditions, Conditions 1 and 2 at feed space velocity of 480 Kg/h/m³ reactor, compared on one-to-one basis, the process performance, product yields and quality between the 'coal-only' feed and the 'coal and mixed-plastic (25 W%)' combined feed (mixed-plastic part of feed was 50 W% HDPE, 35 W% polystyrene, and 15 W% PET). These two conditions established that performance with coal-plastics co-liquefaction was very similar, in terms of conversions and product yields, to direct coal liquefaction, with much improved hydrogen efficiency. Condition 1, with coal-only feed, resulted in about 96% total conversion, 91% resid conversion, and 72% distillate yield (all maf basis); the light gas yield and hydrogen consumption were high (11.4 and 7.5% maf respectively), Condition 2, with 25 W% co-mingled plastics in the feed with coal, resulted in about 96% total conversion, over 85% resid conversion, and 71% distillate yield; thus the overall performance was maintained despite the batch deactivation of the first stage supported catalyst. The light gas yield and hydrogen consumption were also lower during Condition 2 (9% and 6.9% maf respectively).

Condition 3, with higher feed space velocity of 640 Kg/h/m³, higher K-2 temperature, and 25 W% mixed plastics in feed, resulted in a drop in distillate yields and 524°C⁺ resid yield. The solvent-to-feed ratio had to be increased during transition to Condition 4 with 33 W% mixed plastics in the feed and a space velocity of 480 Kg/h/m³. Due to the compensating effects of increased catalyst age (deactivation) in K-1 and reduced space velocity during this condition as compared to the previous one, process performance was maintained. The light gas formation and the hydrogen consumption were lower during Condition 4, probably as a result of the increased plastics concentration in the feed. The last run condition, Condition 5, was similar to Condition 4 in terms of feed space velocity and reactor temperatures although instead of using mixed plastics, pure HDPE alone was used at 33 W% of feed. The overall process performance deteriorated steeply during Condition 5, with distillate yield just over 50 W% maf and resid conversion of 62 W% maf. Overall operations during this run were smooth, except for a few feed pump interruptions. The material balance was excellent (an average for the whole run was 100 W%) and the net recycle solvent-balance was also positive throughout the run.

Bench Run CMSL-09

The objective of CMSL-09 was to evaluate the activity of molybdenum and iron based catalysts for coal liquefaction, as well as for co-liquefaction of coal and plastics. Similar to CMSL-08, CMSL-09 was conducted in a two-stage configuration with an in-line hydrotreater. The feed coal was from Wyoming Black Thunder Mine. The run started in a coal only operation mode. This mode extended over 6 conditions and switched to coal and plastic feed for the remaining 3 conditions. Two levels of con-mingled plastics loadings, 33 and 50 W%, were evaluated in Conditions 7 and 9, while the remaining plastics condition was in HDPE only. A feed space velocity of 640 kg/h/m³ was maintained throughout the entire run. Results of this run are given in Figures 7 to 9. The relative activity of fresh, a mixture of fresh and recycle (only) molybdenum catalysts were

evaluated in Conditions 1 to 3. The distillate yield decreased gradually from the initial level of 66.6 W% to 62.2 W%, while 50% of the fresh Mo catalyst was replaced by recycled catalyst and further reduced to 60 W% when all Mo catalysts were recycled catalysts. A high coal conversion of 95.2 to 95.8 W% was maintained up to 50% of the fresh Mo catalyst was being replaced. At all recycled Mo mode of operation, the coal conversion dropped to 92 W%. The yield of C_1 - C_3 gases and consumption of hydrogen in the "All Recycled" were 1.5 and 1%, respectively, lower than the "All Fresh" case.

During Condition 7, 33 W% of coal was replaced by a mixture of (HDPE/PP/PS) synthesized plastics. The distillate yield increased from low 60% in the case of coal only to 75.4%. This high liquid yield was still observed with 50% of plastics in the feed. The poorer process performance, lower THF and 524°C⁺ conversions, suggested the HDPE was less reactive than PP and PS. Results from this run confirms that co-liquefaction improve the overall process performance by giving higher liquid yield, lower C_1 - C_3 gas make a consuming less hydrogen.

Product Quality from Bench Operations

The separator overhead oil products from CMSL-08 and CMSL-09 represent the net light distillate stream from the process. The overhead stream, which is essentially the liquids boiling between an initial boiling point of about 60°C and 370°C, represents a combination of hot separator (O-1) overhead and continuous atmospheric still (N-1 CAS) overhead streams which passes through an in-line hydrotreating unit, K-3. The product stream from K-3 is designated as the overall SOH (Separator OverHead) product. The other liquid part of the distillate comes from the IBP to 524°C boiling fraction of the pressure filter liquid (PFL) or the vacuum still overheads (VSOH), which are used to constitute recycle solvent, depending upon what is used for solid separation of the CAS bottoms. The properties of Separator OverHeads for CMSL-08 and CMSL-09 from their respective work-up Periods are shown in Figures 3 and 4.

As shown in Table 3, the API gravities and H/C atomic ratios of the SOH oil from CMSL-08 have been high (35-38, and 1.73-1.82 respectively), especially for the coal/plastics coprocessing Conditions. The quality of the distillates is also premium, with less than 10 ppm nitrogen and between 5-15 ppm sulfur contents. The sharp increase in the naphtha (IBP-177°C) fraction during the coprocessing conditions indicates a significant contribution from the plastics part the feed. It was also found that a significant contribution to the resid (524°C⁺) fraction in the product oil was made by the partially or incompletely degraded/depolymerized HDPE. This finding was based upon the waxy nature (solubility behavior) of the pressure filter liquid and the significant rise in both the resid content and API gravity of the heavier oil product when plastic part of the feed was switched over from co-mingled plastics to pure HDPE alone with coal.

Similar findings with regards to the SOH distillate oil properties have been made (Table 4) for CMSL-09. The API gravities (an indication of paraffinic character) of the distillate increased significantly in going from the "coal-only" conditions to "coal/plastics" conditions (from about 32-37 to 40-44). The H/C ratios also improved simultaneously during the transition. The light boiling naphtha (IBP-177°C) fraction increased significantly during the coprocessing conditions, except for the condition that coprocessed coal with HDPE alone, instead of mixed plastics. The sulfur and nitrogen contents of the distillate products have been very low in general, and even lower for the coal/plastics coprocessing conditions.

Thus, both CMSL-08 and CMSL-09 were very successful bench runs from the technical as well as the operational standpoints. A net positive solvent balance (excess production of 343°C⁺ oil over what is needed

for recycle) was obtained for all the operating periods of both these bench runs. Over 22 days of continuous operation was completed without any major issues/interruptions for CMSL-08 (17 days on coal/plastics coprocessing) while CMSL-09 lasted for 41 days of continuous operation (12 days on coal/plastics coprocessing). Samples of different process streams were also obtained for the Consol, Inc. for property characterization/assessment.

These bench runs not only succeeded in providing insights into combined processing of coal with MSW plastics but also indicated the type of reaction severity, reactor configuration, and catalysts needed for achieving near-optimum process performance. The overall process performance, using plastics in the feed with both coals independently, was much better with an improved hydrogen utilization, a significant benefit one strives to derive from the plastics part of the feed in such coprocessing. Secondly, more so with a sub-bituminous coal (CMSL-09), it was found that plastics had synergistic effects on coal conversion in terms of improving the C_4 -524°C premium distillate yields. The presence of an in-line hydrotreater during both the bench operations resulted in light distillate liquids containing as less as 10-25 ppm nitrogen and sulfur. Indeed, it is strongly believed that, because of all the positive effects of coprocessing waste plastics with coal, the economics of coal liquefaction will improve significantly. More importantly, such coprocessing technology would allow re-use of a very valuable hydrocarbon source (waste plastics) into the energy stream, in an environmentally benign manner.

FUTURE PLANS

Run CMSL-10 is scheduled to end during the last week of June. Detailed product characterization will be performed in July and August. Technical and economic assessment of process improvements obtained during this program is under way and scheduled to complete in August. Also, preparation of the final report has been initiated in May aiming to have a draft report for the project in mid-September.

TABLE 1 CMSL-08 RUN PLAN

Coal: Illinois No. 6 Crown II Mine Plastics: HDPE, 50%; PS, 35%; PET, 15% 1st Stage Catalyst: Akzo Ao-Go Extrudate Hydrotreater: Criterion C-411 Catalyst		
Period	Condition	Description
1-6	1	Coal only; Space Velocity of 480 kg/h/m ³
7-11	2	Coal + mingled Plastics, same condition as Condition 1
12-16	3	Coal + 25% Co-mingled Plastics, 25% increase in space velocity
17-20	4	Same condition as Condition 3, with 33% Co-mingled plastics
20-22	5	Same as Condition 4, with 33% HDPE

TABLE 2 CMSL-09 RUN PLAN

Coal: Black Thunder Plastics: HDPE, 40%; PP, 33%; PS, 27% Hydrotreater Catalyst: Criterion C-411 Catalyst		
Period	Condition	Description
1-5	1	Coal only; Fresh Mo only
10-14	3	Coal only; Fresh & Recycle Mo
15-19	4	Coal only; Recycle Mo only
20-24	5	Coal only; Repeat of Condition 3
25-29	6	Coal only; Mo and Fe based catalysts (with recycle)
30-34	7	Coal & Plastics; same as Condition 6
35-38	8	Coal & HDPE; Mo and Fe based catalysts (no recycle)
39-41	9	Coal & Plastics; Mo and Fe based catalysts (no recycle)

**TABLE 3. PROPERTIES OF THE SEPARATOR OVERHEAD DISTILLATES FOR
BENCH RUN CMSL-08**

Run Condition	1	2	3	4	5
Work-Up Period	6	11	16	20	22
W% Plastics in Feed	0	25	25	33	33
Gravity, API	35.4	36.4	37.7	37.6	35.4
IBP, °C	59	79	57	64	77
FBP, °C	366	379	379	377	399
IBP-177°C, w%	28.2	37.1	47.5	37.5	31.6
177-260°C, w%	31.8	22.2	20.9	23.4	24.2
260-343°C, w%	34.3	33.1	24.6	32.4	32.7
343°C ⁺ , 2%	5.7	7.6	7.0	6.7	11.5
H/C Ratio	1.79	1.78	1.73	1.78	1.82
Sulfur, ppm	6	16	5	115	10
Nitrogen, ppm	<1	8	<1	5	4

**TABLE 4. PROPERTIES OF THE SEPARATOR OVERHEAD DISTILLATES FOR
BENCH RUN CMSL-09**

Run Condition	1	3	4	7	8	9
Work-Up Period	5	15	19	34	38	41
W% Plastics in Feed	0	0	0	33	33	50
Gravity, API	37.5	34.5	34.2	39.4	39.9	43.8
IBP, °C	59	61	61	57	72	57
FBP, °C	357	376	379	365	379	379
IBP-177°, w%	35.8	33.1	33.5	43.4	28.2	48.3
177-260°C, w%	23.0	29.8	28.6	24.5	27.6	20.4
260-343°C, w%	32.7	29.9	29.9	26.6	33.3	24.2
343°C ⁺ , w%	8.5	7.2	8.0	5.5	10.9	7.1
H/C Ratio	1.81	1.72	1.72	1.76	1.87	1.82
Sulfur, ppm	7	15	9	9	17	34
Nitrogen, ppm	<1	36	61	47	24	10

Figure 1

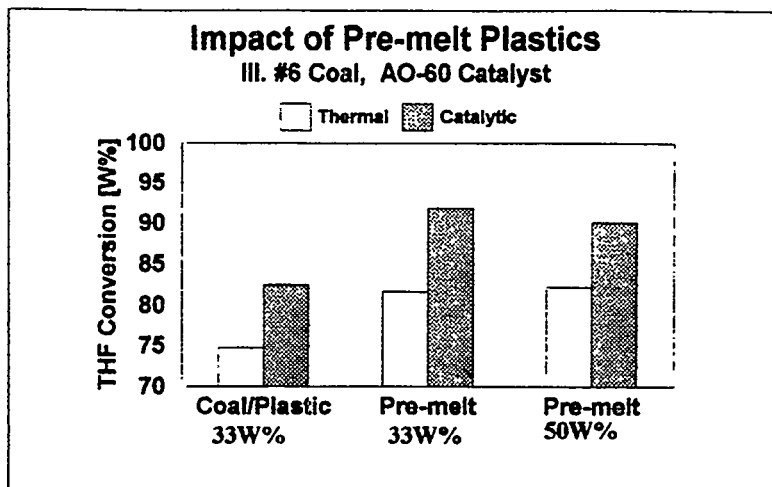


Figure 2

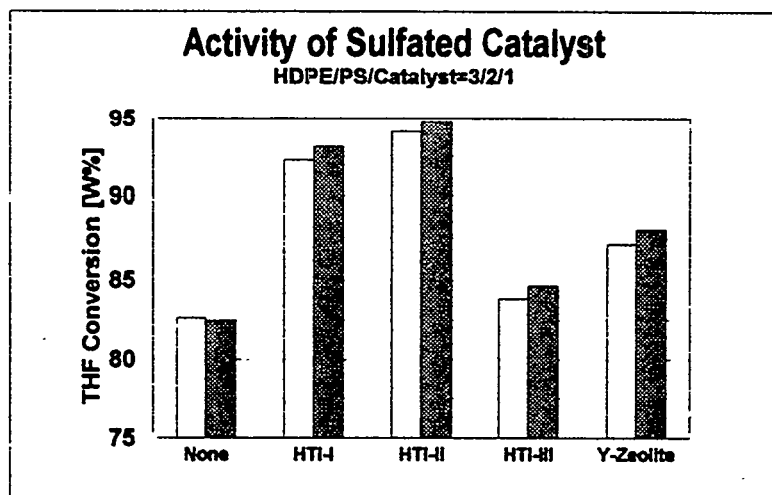


Figure 3

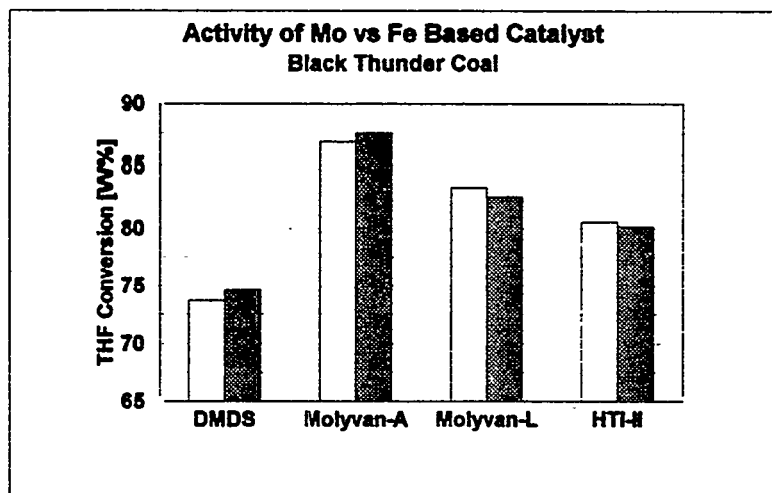


Figure 4

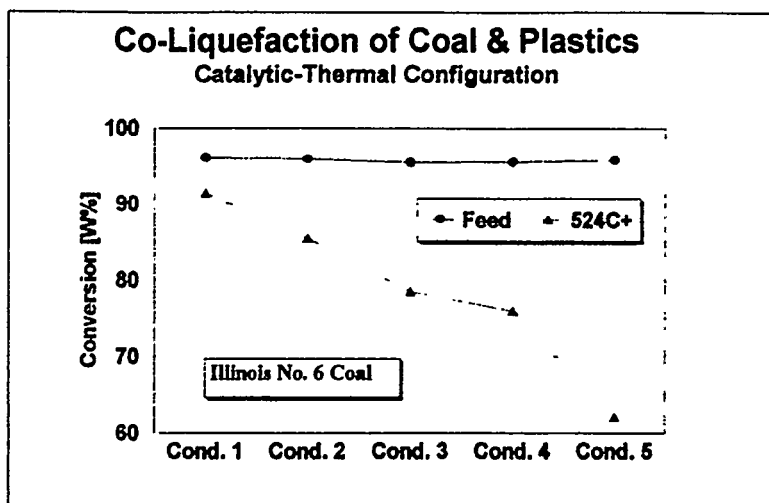


Figure 5

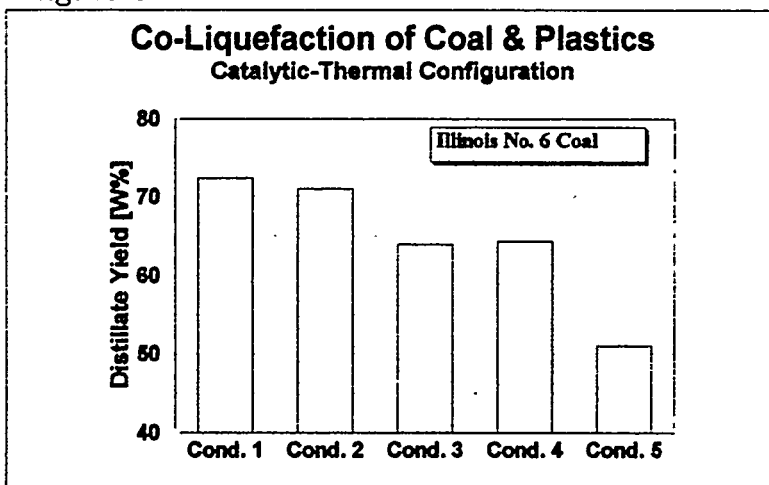


Figure 6

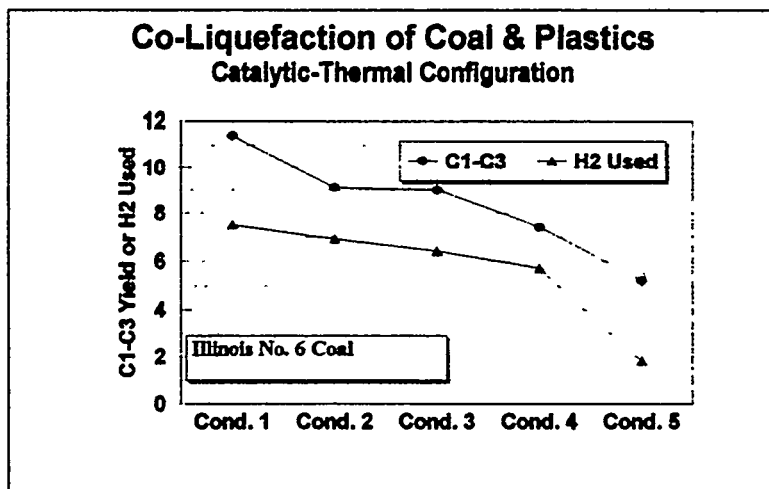


Figure 7

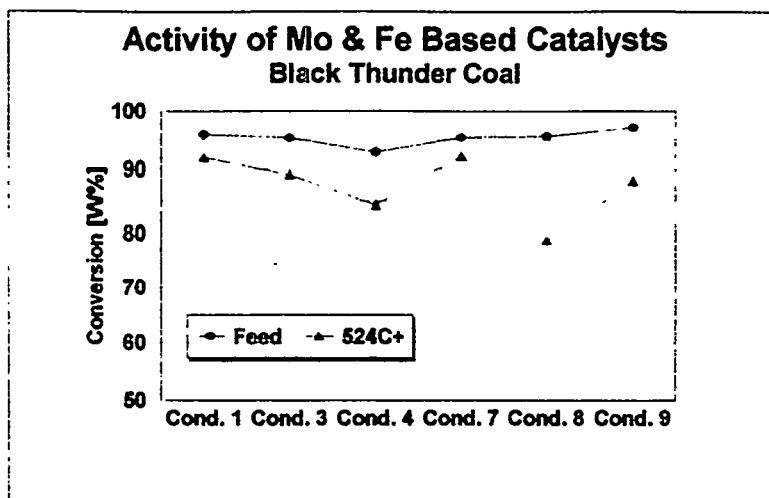


Figure 8

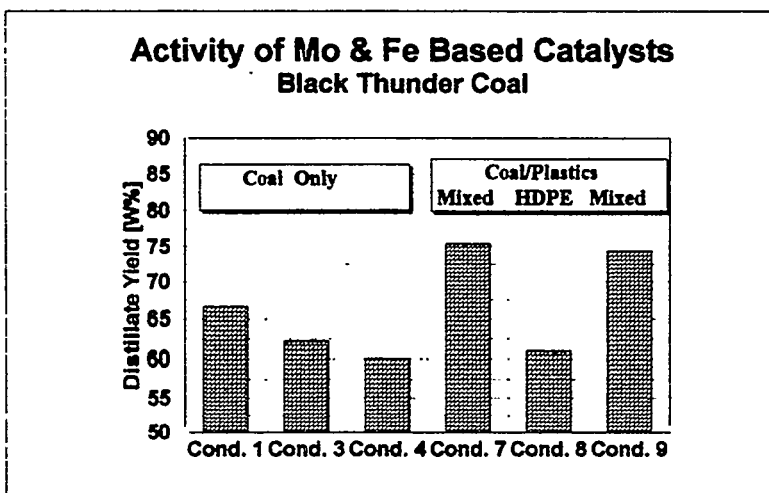


Figure 9

