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**DEVELOPMENT OF BIOLOGICAL COAL GASIFICATION
(MicGAS PROCESS)**

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**DEVELOPMENT OF BIOLOGICAL COAL GASIFICATION
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Tasks 1 and 2:

These tasks have been completed.

Task 3 - Coal-Microbial Interactions:

Subtasks 3.1 - 3.2

These subtasks have been completed.

Subtask 3.3 - Solids Loadings

No work was scheduled in this subtask.

Task 4 - Biological Production of Methane from Coal: Optimization of the Process:

Subtask 4.1 - 4.4

No work was scheduled for these subtasks.

Subtask 4.5 - Bioreactor Studies

Effect of 5% and 10% coal solids loadings was studied in two types of bench scale bioreactors and in chemostat cultures. The bench scale reactors used were - rotating biological contactor (RBC) and upflow bioreactors. In RBC, Texas lignite was loaded at 0% and 5% (w/v), while in the upflow and chemostat reactors - at 0%, 5% and 10%. Methane, total gas production, soluble carbon and volatile fatty acid production (VFA), as well as microbial growth (measured as cell protein) were monitored.

Gas analysis of the headspace from the above mentioned reactors showed higher CO₂ production in experiments with 5% and 10% coal solids (for example, Figure 1). This indicates that acetate degraded into CO₂ but there was not enough hydrogen to carry out the reaction to convert CO₂ to CH₄. These data obtained confirmed our previous results from laboratory scale reactors, that at coal solids loadings higher than 1%, methane production does not enhance significantly. This phenomena could be due to the production of higher quantities of inhibitory compounds or depletion of factors necessary for methanogenesis.

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The influence of ammonium chloride on microbial production of VFAs and methane was studied in chemostat cultures containing 0% and 10% Texas lignite (Figures 2 and 3). Gas analysis of the headspace showed high CO₂ production (513 ml) in experiments with 10% coal and extra ammonium chloride (Figure 3A). However, lower methane production was observed compared to the cultures with NTM + Sheftone T medium (Figure 3B). This is yet another confirmation of our hypothesis that at higher coal concentrations the CO₂ production is enhanced. The control (no coal) reactor produced lower volume of total gas and contained low concentrations of methane and carbon dioxide (data not shown). The lower methane production in the 10% coal reactor may be due to the lower pH (6.5) of the liquid phase, as methanogens are generally inhibited by low pH. The low pH is probably due to the higher carbon dioxide concentration.

Further investigation to confirm utilization of coal by Mic-1 culture was conducted in three upflow reactors containing 0% and 5% (w/v) Texas lignite in NTM + 0.2% Sheftone T and ammonium chloride (32 g/l) medium. Reactor 1 was control (without Texas lignite), reactor 2 contained 5% Texas lignite + 0.5% methanol (added as inducer for methane production and hydrogen donor for biogasification), and reactor 3 - only 5% Texas lignite. During the first 9 days of operation, the total gas production and methane concentration in the head space of reactor with methanol were highest (1865 ml and 1343 ml, respectively). The peak in methane production during the first 10 days (Figure 4A) could be explained as the initial effect of addition of easy to metabolize co-substrate. Thus, in this reactor, the higher methane production observed during the latter part of the experiment was due to biogasification of Texas lignite solids loadings. This is confirmed by comparing the volumes of cumulative methane produced in the reactor that did not contain methanol and the one that did (Figure 4B). Total gas production was similar in reactors 1 and 3, but methane production was observed only in the upflow reactors containing coal. The net methane production was highest in the reactor 2 (1344 ml) and significantly lower in the reactor 3 (~ 93 ml). Differences in microbial growth and soluble carbon were not significant. As compared to other reactors, the addition of extra ammonium chloride to the medium showed significant increase in acetic, isobutyric, butyric and isovaleric acids production in the control reactor. Acetic and propionic acids were higher in the reactor with Texas lignite and methanol (Figure 5), while in reactor 3 the quantity of all VFA was lower and isobutyric and butyric acids were not observed (Figure 6).

To evaluate the effect of solids loadings on survival of methanogens, fresh inoculum (10%, v/v) containing mixture of known methanogens was added on day 25 to provide viable methanogens. Methane production (337 ml) increased only in reactor 3, containing 5% Texas lignite (Figure 4B).

Conclusions:

- Methane production is inhibited in the presence of extra (32 g/l) ammonium chloride in the NTM + Sheftone T medium.
- As compared to RBC, higher methane production was observed in upflow and chemostat reactors with higher solids loadings of Texas lignite.
- Methanol at low concentrations (up to 0.5%) can be used to initially facilitate the methane production from coal by the Mic-1 consortium.

Planned Future Work:

- Evaluate various bioreactor configurations with high coal solids loadings,
- Study the effect of higher methanol concentrations on coal biogasification,
- Study the influence of citrate and cations.

Figure 1. Biogasification of Texas Lignite in Rotating Biological Contactor (RBC) in NTM + 0.2% Sheftone -T Medium : A - Cumulative Biogas Production, c.c; B - Cumulative Methane Production, c.c.

Figure 2. Production of VFA (ppm) in Chemostat Cultures with NTM + 0.2% Sheftone T and extra Ammonium Chloride: A - Control; B - 10% Texas Lignite

Figure 3. Biogasification of Texas Lignite in Chemostat Cultures with NTM + 0.2% Sheftone T and NTM + 0.2% Sheftone T + extra Ammonium Chloride: A - Cumulative Biogas Production; B - Cumulative Methane Production

Figure 4. Biogasification of Texas Lignite in Fluidized Bed Upflow Bioreactors by Mic-1 in NTM Sheftone -T Medium and 4 X Ammonium Chloride. Methane produced in Control (Without Texas Lignite) has been Deducted. A - Actual Production, B - Cumulative Production

Figure 5. Biogasification of Texas Lignite (5%) and VFA Production in Fluidised Bed Upflow Bioreactor by Mic-1 Culture in NTM Sheftone T Medium + extra Ammonium Chloride and 0.5% Methanol: $\square$ Cumulative Methane; $\blacksquare$ Biogas ($\text{CH}_4 + \text{CO}_2$); $\circ$ Acetic Acid; $\bullet$ Propionic Acid; ∇ Butyric Acid

Figure 6. Biogasification of Texas Lignite (5%) and VFA Production in Fluidised Bed Upflow Bioreactor by Mic-1 Culture in NTM Sheftone T Medium + extra Ammonium Chloride: □ Cumulative Methane; ■ Biogas (CH₄ + CO₂); ○ Acetic Acid; ● Propionic Acid; ▽ Butyric Acid

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