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Energy from Sewage Sludge under Thermophilic Conditions

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Background

- Sewage sludge is a massive global environmental problem.
- Methods for sludge removal and treatment are expensive and environmentally hazardous.
- New stringent legislation for sludge removal has fostered the need for innovative technologies to solve this problem.

Existing Methods for Sludge Removal

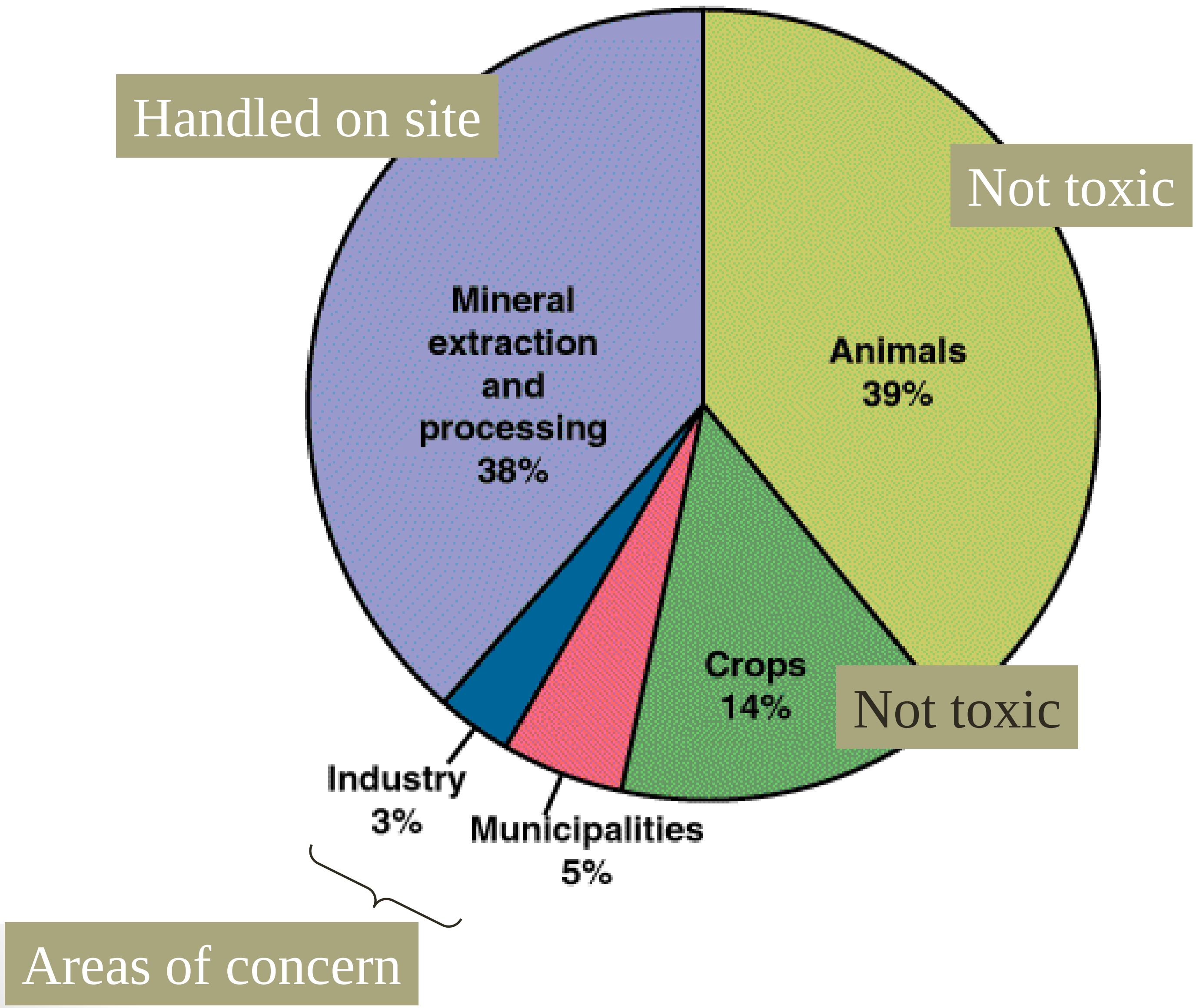
Agricultural use as fertilizer:

Contains toxic materials, heavy metals, pathogens,

Incineration:
Emits dangerous toxics.

Drying and landfill:
Hazardous to the environment.

Principal Sources of Solid Wastes



Sewage Treatment

- Individual scale
  - Settling tank (solids settle and are broken down)
  - Leaching field: receives liquids from septic tank through porous pipes. Bacteria and oxygen breaks down organics and disease causing germs
  - Should have soil layer = 60 cm below 150 cm above
  - Should not be within 15 m of any water body
  - 0.5 to 1 acre per dwelling

So, what is the important point?

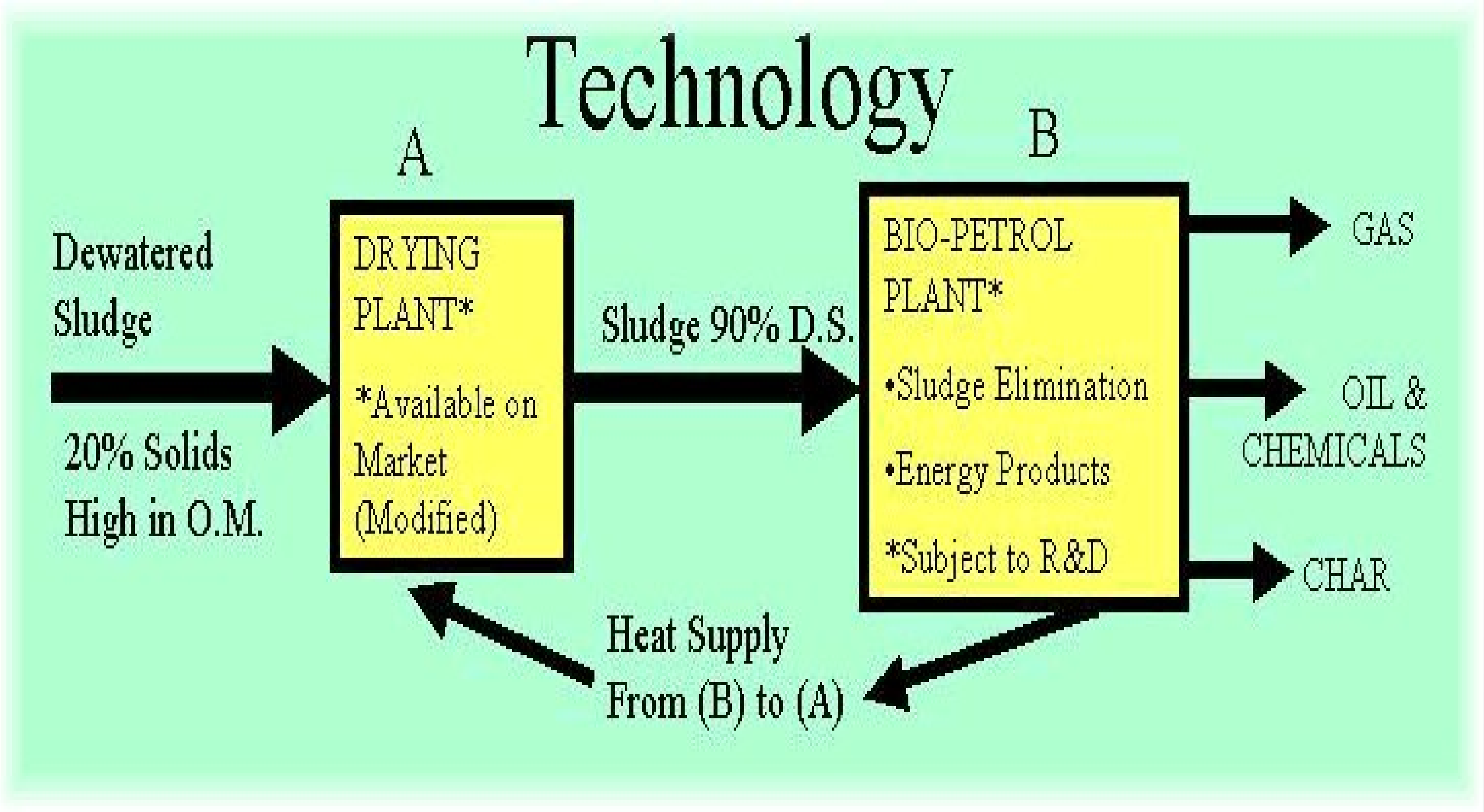
…To develop an efficient, economically viable industrial facility for treating sewage sludge, obtained from urban wastewater treatment plants (WWTP).

Waste Exchange

For example…

- Waste for one person can be raw material for another
- Isopropyl alcohol may be used as cleaning solvent
- Nitric Acid from Electronic Industry may be used as high grade fertilizer
- etc…

… energy from sweage!!



In this study

- It is expected to address the problems associated with waste activated sludge disposal through simultaneous generation of clean gaseous energy in the form of hydrogen.

- A synchronous objective was to investigate the usability of sewage sludge, at the stable thermophilic temperature and different pH conditions in the biohydrogen production by dark fermentation.

- Biohydrogen production could be enhanced and maintained stable by the combination of suitable fermentation temperature and pH.

- The impacts of different pH values (4-9) on hydrogen production under thermophilic conditions will be discussed in detail.

Anaerobic Fermentation of the Sludge

- Activated sludge used was obtained from return sludge pumping station of a sewage treatment plant located in Bafra, Samsun and its characteristics are shown in Table 1.

- The collected sludge samples were gravitationally settled for about 2-3 days and the sediments were stored at 4°C before being used.

Table 1. Mean characteristics of activated sludge used in experiments

Item	Value (mg L^{-1})
pH	6-7
Tprotein	7037
Sprotein	157
Tcarbohydrate	1474
Scarbohydrate	16.5
TCOD	16394
SCOD	316

- Before the anaerobic fermentation, pH of samples was adjusted from 4 to 9 with 4 M NaOH or 2 M HCl.

- No extra-seeds and extra-feeds were added into these reactors. The bioreactor was equipped with two ports for gas and sludge sampling.

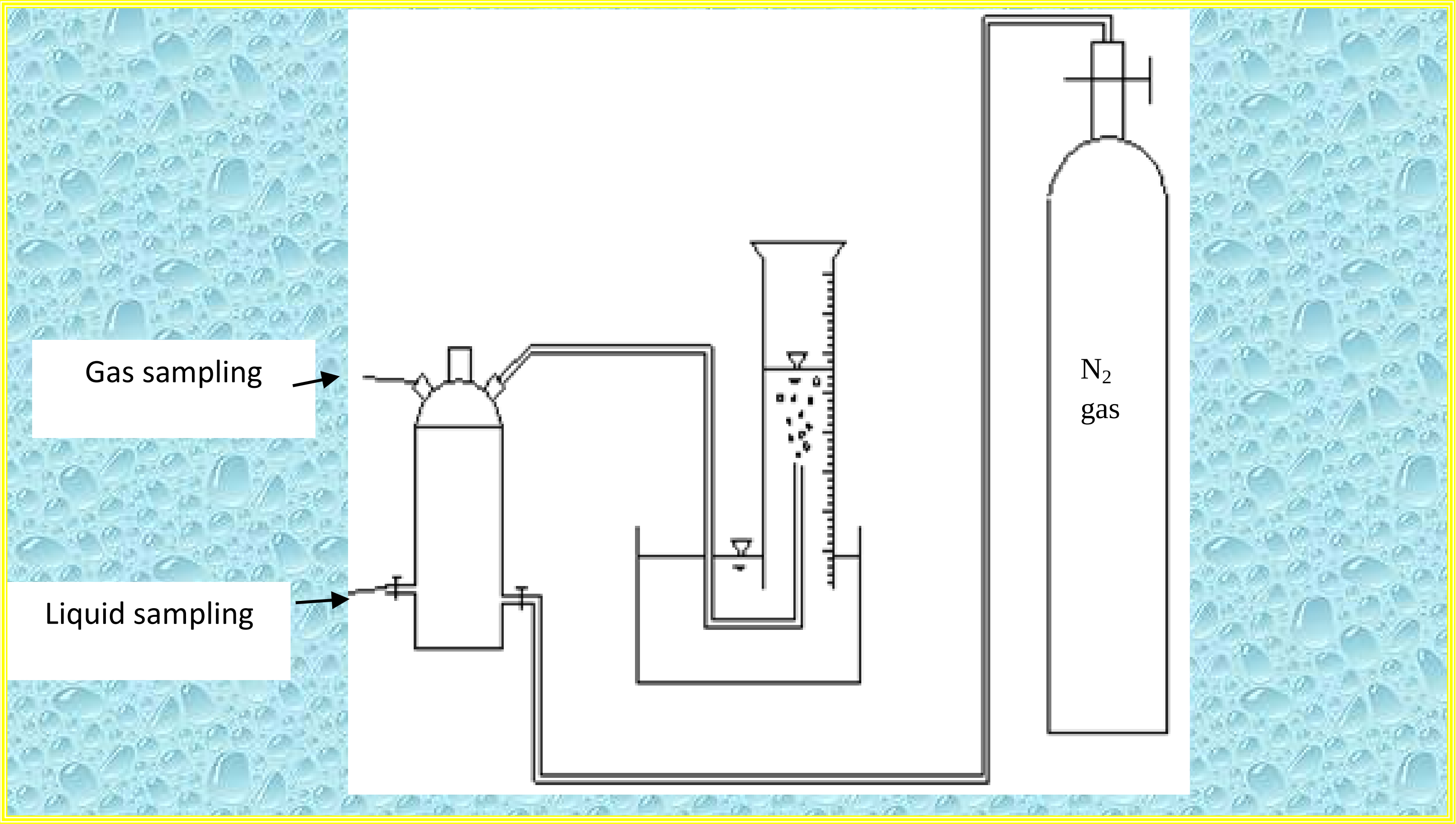
- The internal part of the reactor was purged with nitrogen gas for every 3 minutes to provide anaerobic conditions.

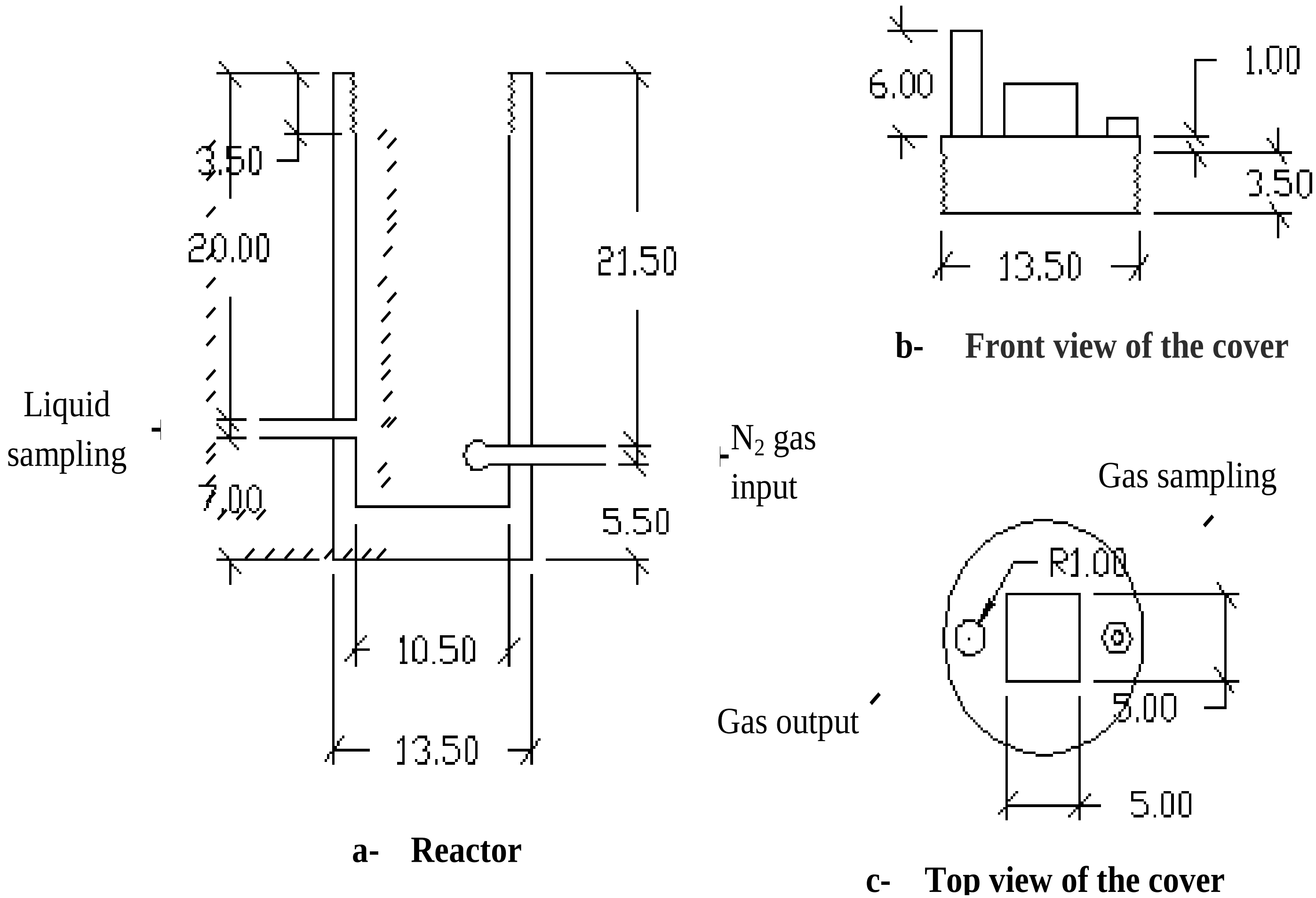
- In the whole process; pH, COD, protein and carbohydrate concentrations of the influent and effluent samples were monitored every day with the hydrogen and methane concentration.

Analytical Methods

The measured values were expressed as mL m^{-3} (ppmv = gas gas^{-1}). The characteristics of the sludge in the fermenter was identified for various time points both before and after fermentation. All experiments continued until hydrogen production stopped or decreased.

Reactor constructed for this study





Reactor used in fermentation experiments

Results and Discussion

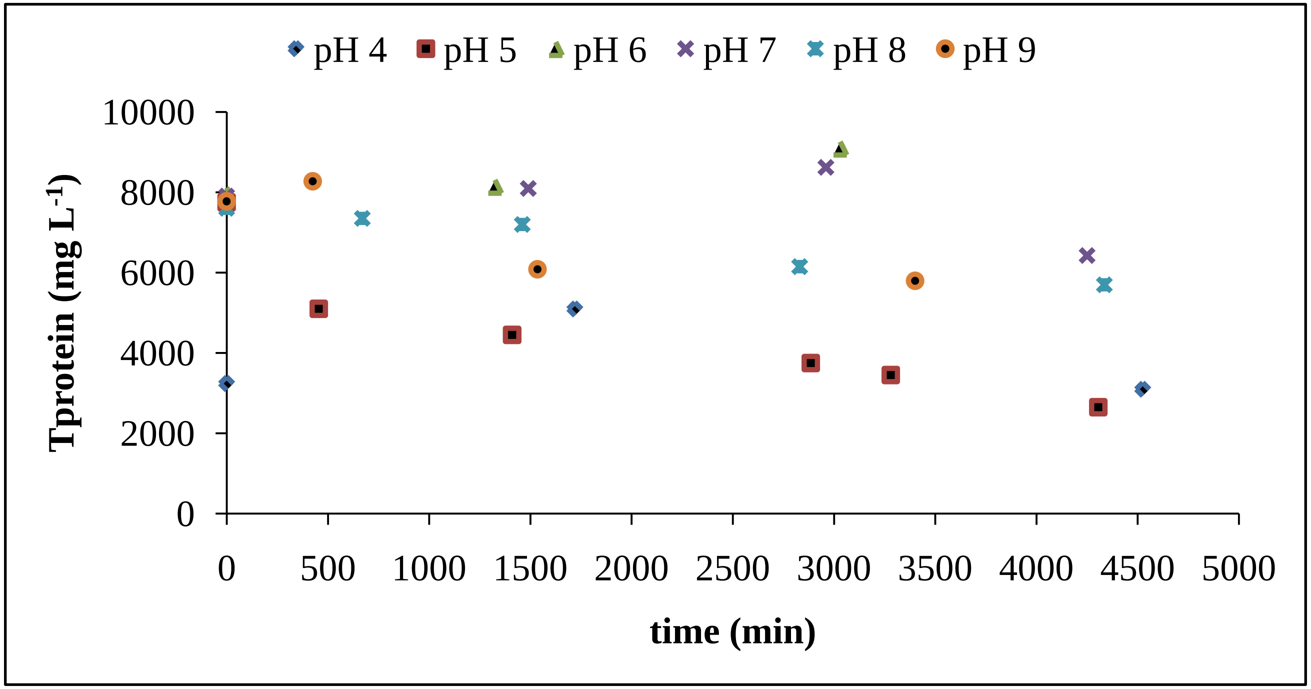


Fig. 1. Alterations in Tprotein concentration in the reactor during fermentation depending on the pH

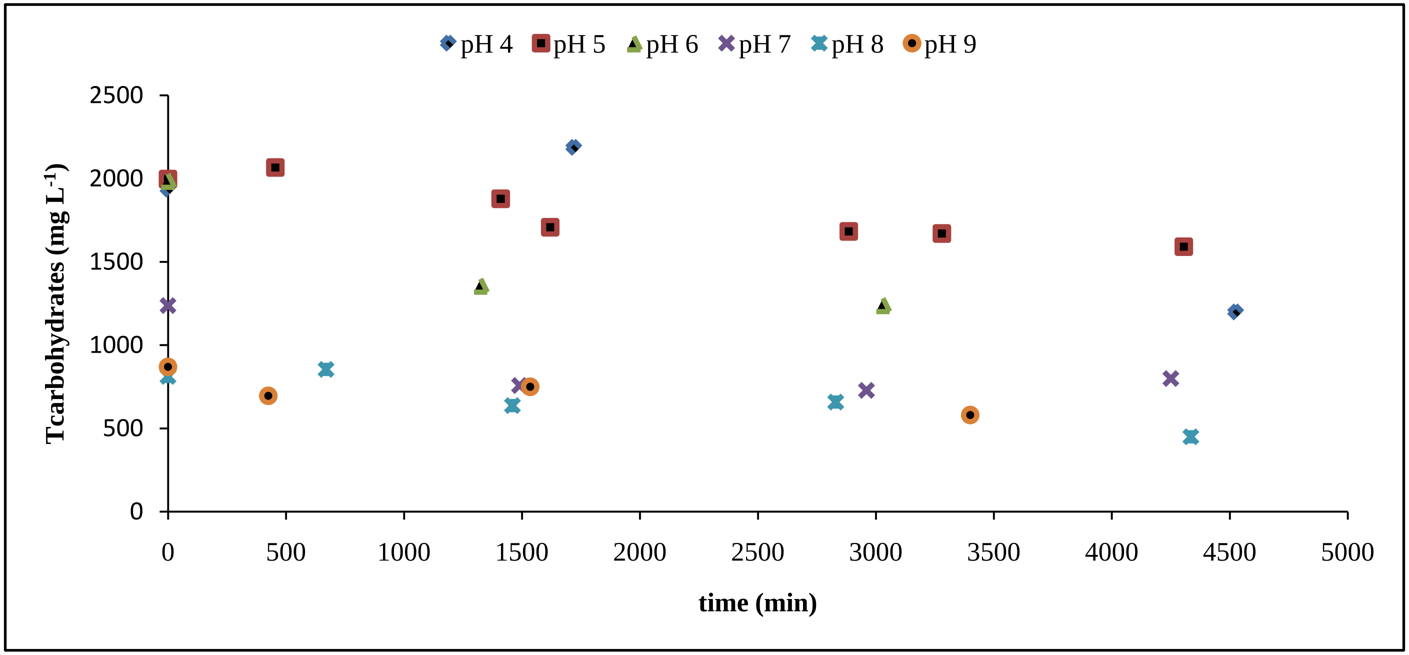


Fig. 2. Alterations in Tcarbohydrates concentration in the reactor during fermentation depending on the pH

- Due to hydrolysis, Tprotein and Tcarbohydrates concentration increased within the first 24 hour and then decreased at pH 4 (Figs. 1, 2).

- The changes occurring in the concentrations during fermentation are due to the balance between the amounts released from the solid phase and that consumed.

- Protein and carbohydrates are consumed during hydrogen production. Therefore, hydrolysis, a phase occurring between anaerobic fermentation and biohydrogen production, plays an important role in the release of organic matters in the solid phase.

- The general result: Tprotein, Tcarbohydrates and TCOD concentrations decreased with time at pH 6, 7, 8 and 9.
- However, at pH 6, exceptionaly, Tprotein concentration increased from 7952 mg L^{-1} to 9095 mg L^{-1} after ~ 51 hours fermentation.
- The solute concentrations generally increased in the first days of fermentation and then decreased in time.
- The alteration in the concentration is a factor that affects biohydrogen production.

- pH studies using untreated sewage sludge show that Sprotein, Scarbohydrate and SCOD concentrations reach their maximum concentrations within first 24 hours due to hydrolysis.
- Despite gradually decreases in the concentration in time, the concentrations at the end of the test were higher in comparison to baseline in almost all tests (except for Sprotein concentration in the reactor at pH 5 and pH 7).
- The result shows that not all dissolved organic matter was converted into the hydrogen.
- In this study, we observed that dissolution of proteins was higher than that of carbohydrates during fermentation. Similar results were reported in literature.

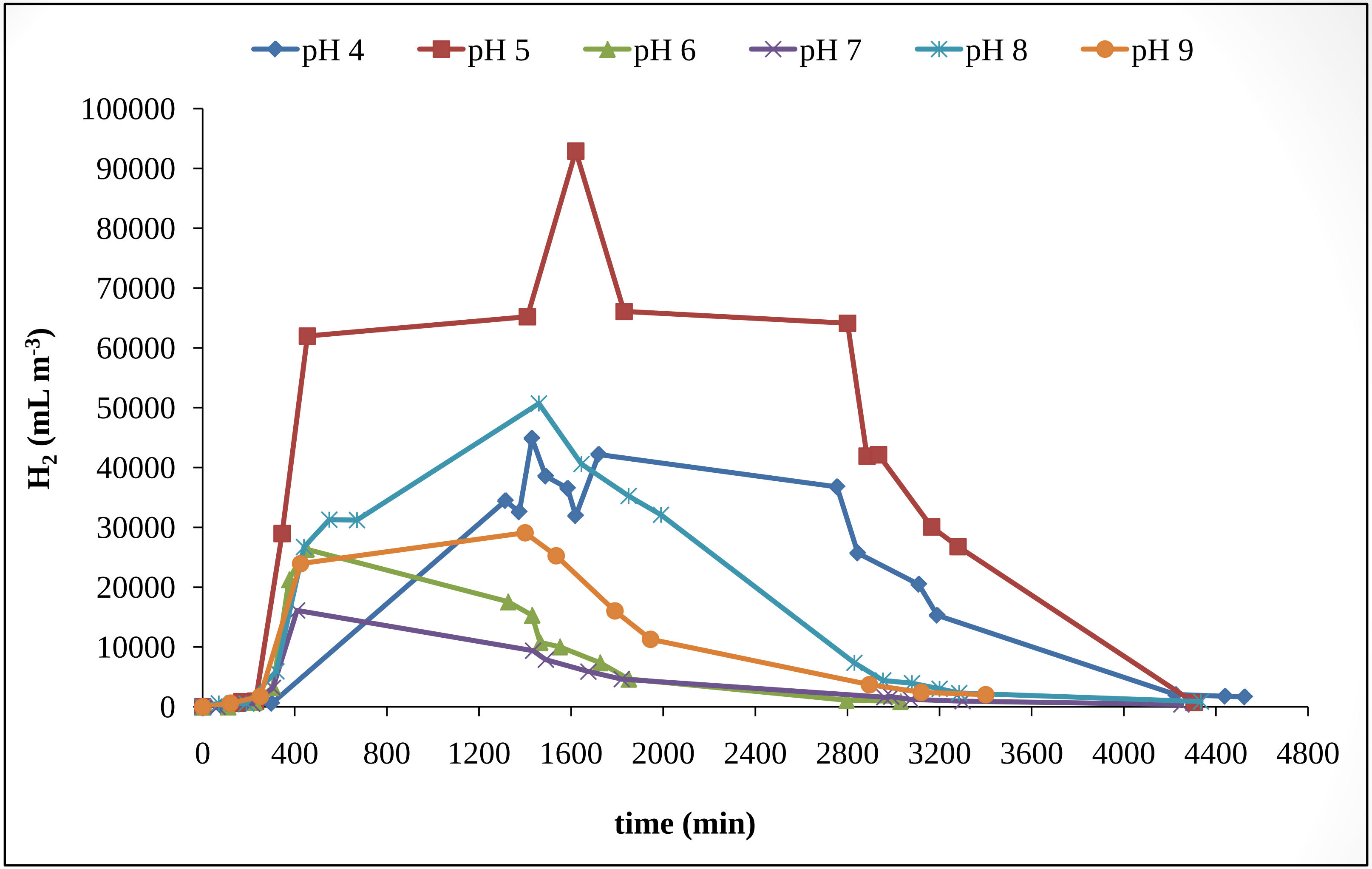


Fig. 3. Hydrogen concentrations obtained at different pH values

- In Figure 3, hydrogen concentrations obtained as a result of anaerobic fermentation studies conducted at 45±1 °C with different initial pH values are given.

- Chemical and biological contents of the substrate may be led to the shortening of the time. In all pH tests, hydrogen concentration in the gas phase showed a fluctuating curve with peaks observed between 7 and 24 hours. This shows that significant amount of hydrogen produced is consumed somewhat.

- Usually at very low hydrogen concentrations, the hydrogen consuming methanogenic bacteria can convert the formed hydrogen to methane if the methanogenesis step goes smoothly. This also causes a rapid decrease in the amount of hydrogen.

The Relationship between pH, Rate of Solubility, and Hydrogen Production

Table 2. SCOD/TCOD (%) in the mixture liquid before fermentation (I) and after fermentation (II) at different initial pH values (the end of approximately 66 hour fermentation)

Initial pH	I SCOD/TCOD (%)	II SCOD/TCOD (%)
4	3.08	25.45
5	1.17	25.45
6	0.78	20.00
7	1.35	26.13
8	0.50	13.33
9	4.00	22.22

- In Table 2, SCOD/TCOD (%) rates which were obtained at the end of approximately 66 hour fermentation were calculated and compared with the values that were calculated before fermentation. In order to determine that whether alterations in SCOD/TCOD ratio (%) has an influence on hydrogen gas release, the data in Table 2 were compared with the hydrogen concentration graphs.
- In all tests, except for pH 8, SCOD/TCOD ratio rose above 20% but remained 13.33% at pH 8. Despite this lower rate at pH 8, hydrogen concentration was higher.
- At pH 7, hydrogen gas concentration was at the lowest level. From the results, we can conclude that increase in SCOD/TCOD ratio is not proportional to the increase in the hydrogen gas concentration. Therefore, it is clear that not all organic matter released from sewage sludge convert into hydrogen by anaerobic fermentation.

- We observed that when initial pH is between 7 and 9, pH value decreased at the end of fermentation but increased at pH values ranging from 4 to 6. The differences in the change of pH were concerned with the SCOD of the sludge samples since the productions of VFA and NH_4^+-N is the result of organics (SCOD) degradation.

- In all the tests, at the end of 2-3 hours, hydrogen production started. Depending on initial pH, hydrogen production at the end of 24 hours is as follows;

pH 5> pH 8> pH 4> pH 9> pH 6> pH 7

- Maximum yield was obtained at the 24-30th hours of fermentation at pH 5 (92894 mL m^{-3} H_2).

- At pH 6, 7 and 9, a rapid consumption in the amount of hydrogen in the reactor was observed after the first 4 hours. At the same time, the highest methane production was obtained at pH 6, pH 9 and pH 7, respectively.
- Hydrogen gas production and consumption ranking revealed that better results were obtained in studies using initial pH value of 5.
- Although hydrogen is produced at pH 8, a rapid decrease was observed in hydrogen production in a short period of time.
- pH values of 5 and 6 were preferred in most of the studies on fermentative hydrogen production.

- pH value also influence the solubility of organic matters found in sewage sludge structure. Higher solubility was obtained at pH 5 compared to other pH values. At pH 5, protein, carbohydrate and COD in the structure of the sewage sludge become more soluble and increased hydrogen production efficiency.
- Additionally, because methanogenic activity decreased or stops at pH values lower than 6.3, methanogenic activity is expected to be inhibited at pH below 6. Not surprisingly, the methane concentration remained at lower levels at pH 4 and 5.
- Considering these results and hydrogen production graph given in Fig. 3, it was concluded that setting the pH of reactor contents to 5 would be appropriate.

Conclusion

- Wastewater sewage sludge was preferred as a raw material for biohydrogen production under thermophilic conditions via anaerobic fermentation.

- Total and dissolved substances are used to meet the nutritional needs of microorganisms in the fermentor and consequently this also increases its hydrogen production efficiency. Especially, increase in the amount of Sprotein positively affects hydrogen production.

- Another important factor affecting hydrogen production is SCOD/TCOD ratio. However, this increase is not directly proportional. In this study conducted under thermophilic conditions, solubility was higher at pH 5 in comparison to other pH values suggesting that pH 5 is more appropriate for biohydrogen production.

- It was understood from the results that biohydrogen production varies according to the characterization of activated sludge.
- Future studies should continue investigating the issues such as removal of hydrogen consuming microorganisms from the environment, detainment of methane production and increment of the solubility of the substance in the fermentor.

Thank you for your attention!