# NON-CATALYTIC AND CATALYTIC STEAM GASIFICATION OF SAWDUST

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## Certificate

This is to certify that the thesis entitled "Non-Catalytic and Catalytic Steam Gasification of Sawdust" being submitted by Mr. Harish Chandra Dak to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy in Centre for energy studies and Department of Chemical Engineering, is a record of bonafide research work carried out by him. Mr. Harish Chandra Dak worked under our guidance and supervision and has fulfilled the requirement for the submission of this thesis, which to our knowledge has reached the requisite standard.

The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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## ABSTRACT

The importance of renewable resources like biomass as a raw material for chemical feed stocks and for energy uses have been highlighted in many studies and forms the basic foundation of the present study. In this case experiments have been conducted to convert biomass (sawdust) to synthesis gas, which is used to produce liquid fuels and hydrocarbon gases by Fischer-Tropsch synthesis or methanation reaction. The final product requirements puts certain limitations on the ratio of CO & $H_2$ in the product gas. The prime objective of the present study was to obtain a suitable ratio of CO to $H_2$ in the product gas, with maximum gas yield by using either catalyst or without it and determining the process conditions for obtaining such product yield.

A detailed experimental programme was conducted for gasification of sawdust in presence of steam and with or without various catalyst additives, in the temperature range of 300 - 850$^{o}$ C. Preliminary experiments were also carried out to study the effect of steam flow rate and particle size of sawdust to help in the choice of parameters for final studies. This was particularly important to determine the mass transfer resistance on operation of gasification process.

The experiments with different particle size showed significant effect on gasification, upto the size of 1 mm, indicating presence of diffusional resistance. However, the particles with smaller sizes did not show any effect and was used for an experimental work. This observation indicates that the reaction could be considered as homogeneous one.

The sodium zincate catalyst. enhanced % sawdust conversion and % energy recovery by gaseous products at 850°C upto 95% and 134% respectively in the net input output basis. However, the % energy recovery showed similar enhancement with catalyst CaO + ZnO, as the combined catalyst. This higher than 100% energy recovery suggests that considerable amount of hydrogen have been released from steam, via carbon-steam reaction.

First order kinetics expressions were used to determine the kinetic parameters. The experimental results were plotted for first order simple kinetics. The agreement was in for certain conversion ranges only, indicating a complex multiple path in the reaction mechanism for the gasification reaction.

The Arrhenious plot of the rate constants for simple one step reaction mechanism indicates that there are three different stages of the gasification reactions depending on the reaction conditions i.e. temperature and catalyst contents. A three step gasification reaction model has been developed for the present study. In the first step, the biomass material pyrolyses to yield volatiles (liquid & gas) and solid char products. In the second step, the liquid products of volatile component undergoes secondary reaction with steam and other gas components to form further gases. Simultaneously char also reacts with steam to form gaseous products, in third stage.

The model parameters were determined by using the experimental gasification reaction rate data at different conditions of operation. The complete kinetic rate expressions including Arrhenieous activation energies were also obtained for each parameters.

The model was then used to predict the gasification rate of various process conditions and compared with the experimental data to examine the validity of the model prescribed for the system. Close agreement between the predicted data and the experimental results showed that the model was of sufficiently accurate to represent the gasification reaction processes taking place within the reaction.

It was observed that the gasification rate and total gas yield increased with increase in steam flow rate. The significant effect of steam flow rate was observed up to the steam flow rate of 9 g/min, which corresponds to the maximum vapour velocity of 2.496 m/s at 850°C. The steam flow rate also influenced the composition of product gas yield. The observed increase in the concentration of $H_2$ and $CO_2$, suggested that higher partial pressure of water vapour increases water gas shift reaction, thereby resulting high $H_2$ concentration.

The increase in temperature, increased the gasification rate, increased total gas yield and % carbon in gaseous products alongwith % energy recovery from gaseous products. The temperature also affects the gas composition significantly. The CO & $H_2$ concentration increased significantly with increase in temperature and concentrations of $CO_2$ increased upto a maximum initially and then decreased in the temperature range of 700 - 850° C.

To get proper $H_2$/CO ratio, required for ... Fischer-Tropsch synthesis, few catalysts were added in the form of either insoluble alkali oxides or soluble salt of alkali oxides and salts. The catalysts choosen for the present study were CaO, ZnO, Zinc Formate and Sodium Zincate. In general, these catalysts were used individually, but combination of CaO + ZnO was also studied together, specially to show ... some different specific purposes of the catalyst.

The addition of catalysts enhance ... % sawdust conversion, total gas yield, rate of gasification, % carbon in gaseous products and % energy recovery from gaseous products. It was found that catalysts have influenced gas composition to a great extent and it was possible to adjust the $H_2$:CO ratio with proper choice of certain materials and proper process conditions. Particularly, this phenomenon was observed with the catalysts in the form of zinc salts i.e. zinc formate and sodium zincate.

CONTENTS