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Pyrolysis of Municipal Solid Waste

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Abstract: ***Generally asphalt used by the paving industries today is obtained by processing the crude oils. The price of the crude oil is influenced by the demand of the different grade of crude oil. Due to high prices of crude oil, the price of asphalt binder has increased tremendously. So scientist are looking for the alternative binders and the bio-oil obtained by pyrolysis of municipal solid waste (MSW), is one of them, which can be best utilized for road construction due to which the environmental pollution get reduced and the problem of disposal of MSW get minimized.In view of search of alternative binder for flexible pavement, a research study on 'Effective use of bio oil obtained by pyrolysis of municipal solid waste in flexible pavement' is under taken. The pilot pyrolysis machin of capacity 10 Kg is developed at Transportation Engineering laboratory of Collage of Engineering, Pune. The machine contains reactor, feeder pipe, vapour line, condenser pipe, reciever of bio oil etc. The pyrolysis of various samples of combined municipal solid waste (msw) and waste plastic bags are carried out. It is noticed that the pyrolysis of combined msw occurs at maximum reactor external température of 450°C to 550°C where as the inside température of reactor at which reaction occurs is observed within range of 100°C to 110°C and vapour line temperature was observed between 85°C to 90°C. The various characteristic of bio oil obtained from combined msw are checked. The time study of pyrolysis cycle is taken in which the temperature of reactor, vapour line temperature and inside temperature of reactor are recorded at certain time interval. The physical and chemical characteristics of bio oil of msw shows the ressemblance with the characteristics of bio fuel and bitumen. Due to high water content, the tests of kinematic viscosity and flash point couldnot be conducted. Before testing, removal of water content by distillation of sample is essential. The calorific values will improve after removal of excess water content in bio oil. The FTIR spectra shows the alophatic carboxylic acids and aliphatic hydrocarbons groups which are also present in chemical composition of bitumen. There is future scope for further research and experiments to find out the effective utilization of msw bio oil for replacement of bitumen in flexible pavement.***
Keywords: Pyrolysis, bio-oil, msw, reactor temperature, kinematic viscosity

I. INTRODUCTION

The bitumen used in flexible pavement is obtained from petroleum crude oil. The price of bitumen is increasing day by day. The petroleum crude oil is one of the natural resources and the natural resources are depleting. We need to conserve natural resources. There is huge consumption of bitumen for flexible pavement in all over India. Therefore there is always a search of alternative binder. In Iowa State University, the efforts had been taken to use the bio oil of switch grass, oak wood, cornstover is obtained by pyrolysis to replace bitumen.[2] On the observation of this study, further research is undertaken on the topic 'Effective use of bio oil obtained by pyrolysis of municipal solid waste in flexible pavement'

On the other hand we are facing serious environmental issues due to generation of municipal solid waste in huge quantities. There is no disposal system effectively working. Because of which we are facing problems of health hazards and pollution in all over India. Huge land is occupied for storage due to dumping of municipal solid waste. In order to control the increasing problems of waste, pyrolysis is one of the popular method coming up for pollution free disposal of municipal solid waste. In this method, thermal decomposition is done in absence of oxygen.

The bio oil is produced along with carbon black powder and uncondensed gas. It is proposed to use this bio oil as alternative binder. At the optimum temperature of pyrolysis, maximum out put of oil is obtained.

The municipal solid waste generally contains organic waste, paper, glass, metal, plastic, textile etc ingredients. The glass and metal are separated out and are reused. The plastic household containers and thick plastic bags such as milk bags are also reused. The rest of the waste contains organic waste with plastic thin carry bags, plastic packaging pouches of biscuits, wafers etc, pieces of textile waste, pieces of papers etc.

This waste is called as 'Combined MSW' in this paper. This waste cannot be used anywhere and mountains of such wastes are creating. The peoples handling such type of waste are suffering from health hazards. In big cities it is observed that several acres of land is occupied due to storage of such waste. The effective disposal of this waste is need of society. This type of waste is selected for research purpose.

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II. MATERIALS AND METHODS

A. Equipment Details

A set up of pilot plant of pyrolysis of maximum capacity 10Kg is established at laboratory level. The plant contains reactor, vapour pipe line, condenser pipe, oil receiver, feeder pipe, oil receiving tap etc components. The reactor is made up of material SS316 of dimensions40 cm dia and 75 cm in length. The reactor is surrounded by a coil at a gap of 50 mm from external surface of reactor to which the electrical supply is provided and the reactor is heated by radiation. Three phase electrical supply is provided through the control panel on which the digital readings of various temperatures such as reactor body temperature, inside temperature of reactor and vapour line temperature could be displayed. Three different probes are fitted to sense these temperatures. Maximum temperature of reactor can be reached up to 900°C. The pressure gauge is provided at vapour line to measure and ensure low pressure upto 0.001 mmHg. Water jacketing is provided for effective condensation of vapours. The reactor is fixed whereas the staft with impeller is rotating in forward and reverse direction, the drive is being given through motor and gear box. The feeder pipe of ID 80mm is fitted to reactor thru which the waste material is inserted. A receiver is provided to collect the oil. At the top of receiver an exit pipe is provided to release the uncondensed gases. These gases are allowed to leave into water in order to avoid air pollution. In bigger capacity plants, the uncondensed gases are stored in balloons and reused for heating purpose. At one end of reactor a window with stutter is provided to remove carbon generated in pyrolyis .

Fig 1. Pilot Pyrolysis Plant

The pyrolysis process carried out for 11 different samples of Municipal Solid Waste collected from Karad City of Maharashtra State. The samples were collected from different locations and in different seasons. The usable waste material was already separated out and the rest of the waste was dumped in dumping yard.

B. Experimental Procedure

The samples of municipal solid waste were kept in solar heat for drying. Before pyrolysis the weights of different ingredients in msw are recorded. Ideally waste material shall be cut into small pieces, but in this case pyrolysis was done by processing the material as it was received. The labour involved for segregation and to cut into pieces is more. In actual practice, the segregation at dumping yard and its cutting is time taking and costly. To avoid this, experiment was conducted by processing the msw without cutting into small pieces.

In present study the pyrolysis using reactor described was carried out at 450°C to 550°C at very low pressure with rate of heating 15 °C/min. The waste is converted into bio oil, solid carbon powder and uncondensed gas.

The detail process of pyrolysis of two samples is discussed in this paper along with its time study of pyrolysis cycles. The physical properties of bio oil are checked.

III. OBSERVATIONS

A. Pyrolysis details of various samples of MSW

The following table shows the details of pyrolysis of various samples of msw along with the temperature at which the bio oil generation was started and record of maximum out put of bio oil received.

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TABLE I. PYROLYSIS OF VARIOUS SAMPLES OF MSW

Sr No	Type of Waste processed for Pyrolysis	Quantity of Waste in Kg	Maximum quantity of Bio Oil obtained in %	The temperature of reactor at which Bio oil generation started in°C
1	Household Plastic from MSW	2.469	34	541
2	Combined MSW	2.8	13.39	540
3	Combined MSW	5.6	14.48	515
4	Combined MSW	3.727	13.42	550
5	Combined MSW	3.624	13.32	540
6	Combined MSW	4.603	25.52	543
7	Combined MSW	3.048	32.91	540
8	Wet Organic Sample	3.265	36.97	493
9	Dry Organic Sample	1.8	47.72	500
10	Combined MSW	2.017	18	544
11	Semidry Organic Waste	2.079	43	546

In the pyrolysis of combined msw, the maximum out put of bio oil was 32.91%, in case of organic waste it was 47.72 % and in case of household plastic containers from msw it was 34%. The range of temperature at which pyrolysis reaction occurred and the bio oil generation started was from 493°C to 550°C .

The details of pyrolysis cycle of two samples of msw are studied. The sample was segregated and weights of different ingredients are noted.The time study of pyrolysis cycle is taken in which the température of reactor, vapour line temperature and inside temperature of reactor are recorded at certain time interval.

B. Pyrolysis of MSW- Sample 1 (MSW1)

Sample – Combined Municipal Waste
Collection Site- MSW depot, Karad
Quantity of waste- 5.600 Kg
Quantity of Bio oil obtained - 0.811 Kg – 14.48 %

1) Different Ingredients of MSW sample and its proportion

TABLE II . INGREDIENTS MSW 1

Sr No	Waste Ingredients	Weight in Kg	% of total waste
1	Plastic Bags	0.685	12.23
2	Textile Waste	0.212	3.79
3	Leather Waste	0.138	2.46
4	Rubber sole of footware	0.269	4.8
5	Paper Waste	0.126	2.25
6	Organic Waste & Miscellaneous	4.17	74.47
	Total	5.6	100

Note - Sample Collected from MSW dumping yard, Karad, M..S.(India) The sample was collected in the month May 2017. It was kept for dryng in solar heat for the period of three weeks and processed for pyrolysis on 09.12.2017. The sample was dry at the time of pyrolysis.

2) Pyrolysis Cycle Time Study

TABLE III PYROLYSIS CYCLE TIME

Sr. No	Time Clock Hour (Indian Standard Time)	Reaction Temp in °C	Vapour Temp in °C	Body Temp in °C	Remark
1	9.55	36	15	19	
2	10.25	49	28	390	
3	11.15	95	38	502	Waste Material feeding started
4	11.4	109	71	476	
5	12.05	109	90	510	Emission of uncondensed gases started thru exit pipe.
6	12.2	108	89	514	
7	12.3	110	89	527	
8	12.45	111	89	539	
9	12.55	107	85	515	Bio oil obtained approx - 0.50 Kg
10	13.35	106	87	570	
11	13.45	106	87	574	
12	14.15	111	87	586	
13	14.37	112	87	588	
14	14.47	120	88	588	
15	15.05	126	89	588	
16	15.15	131	91	587	
17	15.4	140	92	588	Bio oil obtained 0.811 Kg - 14.48 %

From Table III it is noted that,

a) Pyrolysis Process Cycle Time for optimum yield – 3 Hrs
b) Reactor Temperature at max yield of bio oil - 515°C
c) Reaction Temperature – 107 °C
d) Vapour Temperature- 85°C

3) Graph of Pyrolysis Cycle

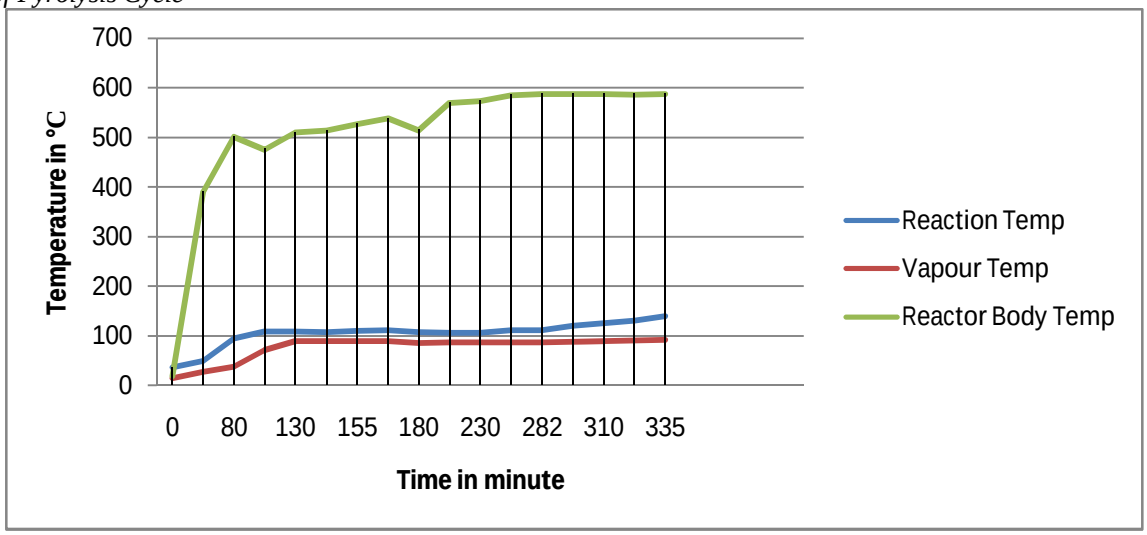

Fig 2. Time v/s Temperature of Reaction, Vapour Line, Reactor Body

Fig 3. Combined MSW -- 5.600 Kg

Fig 4.Total Bio oil obtained- 0.811 Kg – 14.48 %

C. *Pyrolysis of MSW Sample 2 (MSW 2)*

Sample- Combined Municipal Solid Waste – Semidry

Collection spot- MSW Depo Karad

Quantity of Waste- 3.727 Kg

Quantity of Bio Oil obtained – 0.50 Kg – 13.42 %

1) Different Ingredients of MSW sample and its proportion:

TABLE IV. INGREDIENTS OF MSW 2

Sr. No	Waste Ingredients	Weight in Kg	% of Total waste
1	Plastic waste	0.317	8.5
2	Textile Waste	0.48	12.89
3	Leather Waste	0	0
4	Paper Waste	0.387	10.38
5	Organic Waste & Miscellaneous	2.543	68.23
	Total	3.727	100

Note –The sample was collected in the month Oct 2017. It was kept for dryng in solar heat for the period of three weeks and processed for pyrolysis on 15.12.2017. The sample was dry at the time of pyrolysis.

2) Pyrolysis Cycle Time Study:

TABLE V PYROLYSIS CYCLE TIME

Sr. No	Time Clock Hour(Indian Standard Time)	Reaction Temperature in °C	Vapour Temperature in °C	Body Temperature in °C	Remark
1	9.25	35	14	18	
2	9.35	39	18	173	
3	9.45	43	23	294	
4	9.5	45	24	332	
5	10	47	28	400	
6	10.1	49	30	435	
7	10.2	53	32	466	
8	10.3	56	33	487	
9	10.4	60	34	496	
10	11	75	43	513	Waste Material feeding started
11	11.1	81	48	518	
12	11.25	97	52	525	
13	11.3	102	63	527	
14	11.4	104	82	536	

15	11.52	101	79	543	
16	12.02	103	90	550	Bio-oil obtained
17	12.15	103	88	557	
18	12.2	106	89	560	
19	12.3	106	91	564	
20	12.4	109	91	563	
21	12.45	110	92	563	
22	12.55	112	94	566	
23	13.1	115	95	575	Bio oil obtained - 0.500 Kg - 13.42 %

From Table V it is noted that ,

a) Pyrolysis Process Cycle Time for optimum yield – 2.5 Hrs
b) Reactor Temperature - 550°C
c) Reaction Temperature – 103 °C
d) Vapour Temperature- 90°C

3) Graph of Pyrolysis Process Cycle

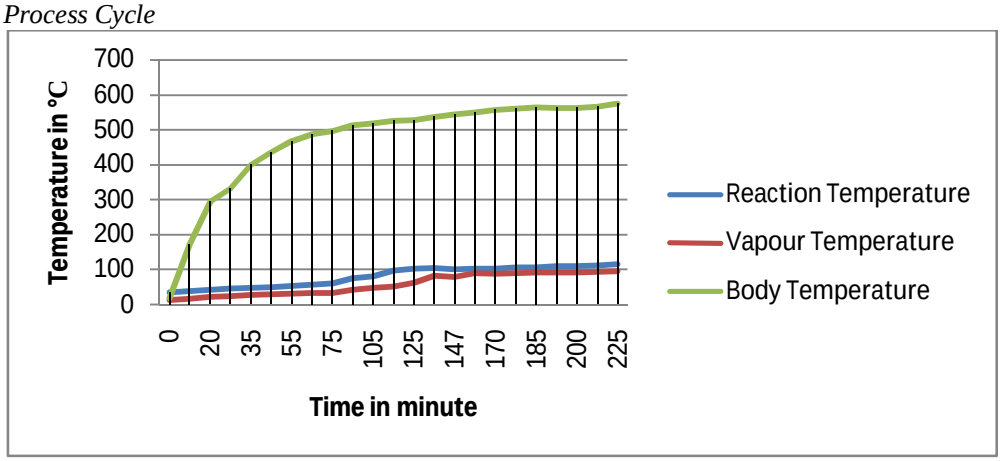

Fig 5.Time v/s Temperature of Reaction, Vapour Line, Reactor Body

4) Images of MSW sample and its bio oil:

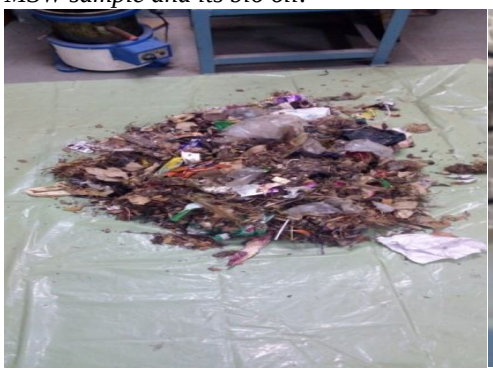

Fig 6. Combined MSW

Fig 7.Total Bio oil obtained- 13.42 %

IV. RESULTS AND DISCUSSION

From the above two pyrolysis cycles of Municipal Solid Waste samples it is noticed that the pyrolysis of combined msw occurs at maximum external température of reactor between 450°C to 550°C where as the inside temperature of reactor at which reaction occurs is observed within range of 100°C to 110°C and vapour line temperature was observed between 85°C to 90°C. After recieving bio oil, if the heating is continued , the temperature of reactor goes on increasing. The total pyrolysis process continues

from 2.5 Hr to 3 Hr. It is observed that the thermochemical reaction occurs within 30 to 35 minutes time But in case of contineous operation of pyrolysis, the heating time of reactor is reduced up to 60 minutes. This will save the energy required for pyrolysis.In above cases the quantity of bio oil are recorded as 14.48% and 13.42 % . But when the bio oil is settled in bottle for one or two hour it is noticed that there are two layers formed in oil, the top layer is of oil and bottom layer is of water. Apprximately 50 % water was found in total quantity of bio oil obtained. The water was removed before testing of bio oil

A. Characteristics of Bio oil derived from Combined Municipal Solid Waste-

1) Testing of various characteristics of bio oil derived from Pyrolysis of Combined MSW is carried out for above mentioned two samples -MSW1 and MSW2

2) The characteristics are compared with the ASTM D7544-12 specifications of liquid bio fuel, published in 2012.

TABLE VI . CHARACTERISTICS OF MSW BIO-OIL

Sr. No	Test Description	Unit	MSW 1	MSW 2	Limit as per ASTM D7544-12 Specifications
1	Density at 15 °C	Kg/m3	953.1	973.1	1100 min
2	Gross Calorific Value	Cal/g	2360	2100	3585.08 min
3	Flash Point	deg C	*	*	45
4	Water Content	% by Vol	52	76	30 max
5	Pour Point	Deg C	0	0	-9 min
6	Ash Content	% by wt	0.130	0.243	0.25 max
7	Kinematic Viscosity at 40°C	cSt	*	*	125 max
8	pH Value		4	4.20	-
9	Total Sulphur	% by wt	0.196	0.209	0.05 max
10	Conradson Carbon Residue	% by wt	0.84	1.71	-

*Because of high water content, the tests could not be conducted. The sample may require pre-heatening treatment before testing.

B. Graphical representation of Characteristics

The graphical comparison of various characteristics of bio oil of MSW1 & MSW2 with ASTM D 7544-12 specifications is shown in following charts.

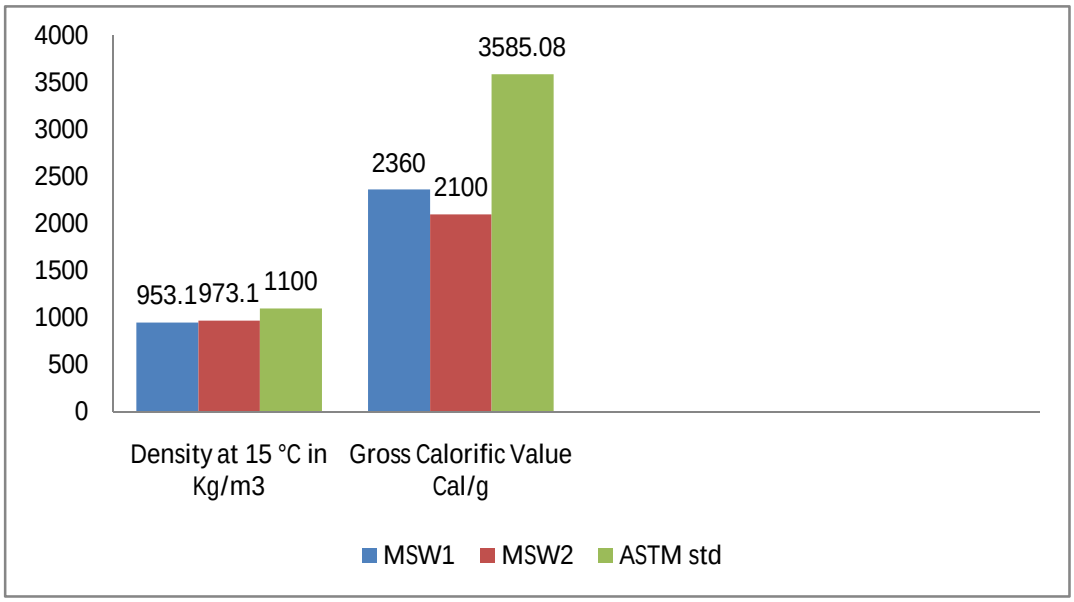

Fig 8. Comparison of Density and Calorific value of MSW bio oil with ASTM specification.

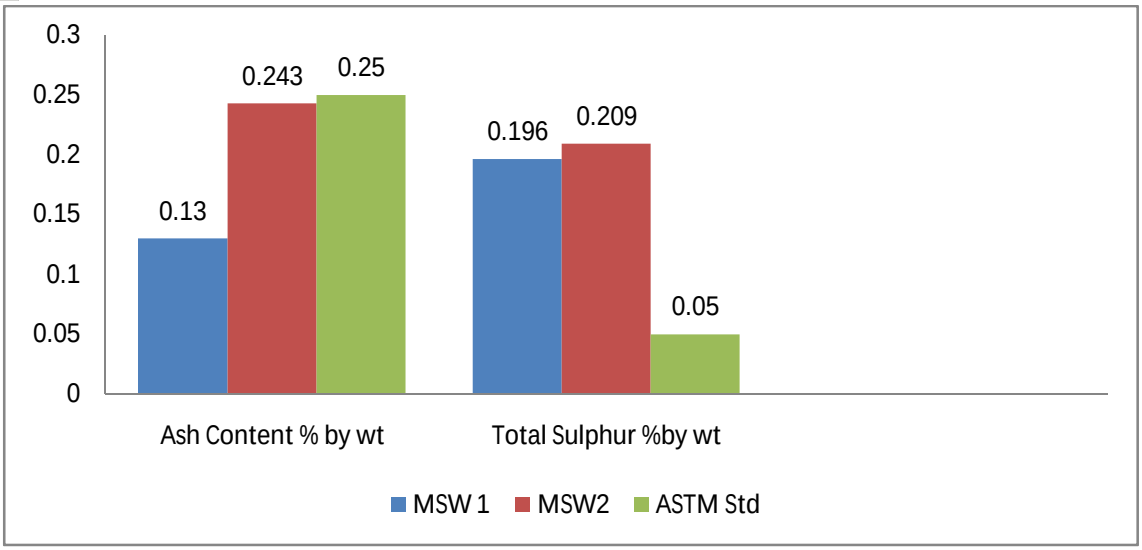

Fig 9 : Comparison of Ash content and Total sulphur content of MSW bio oil with ASTM specification

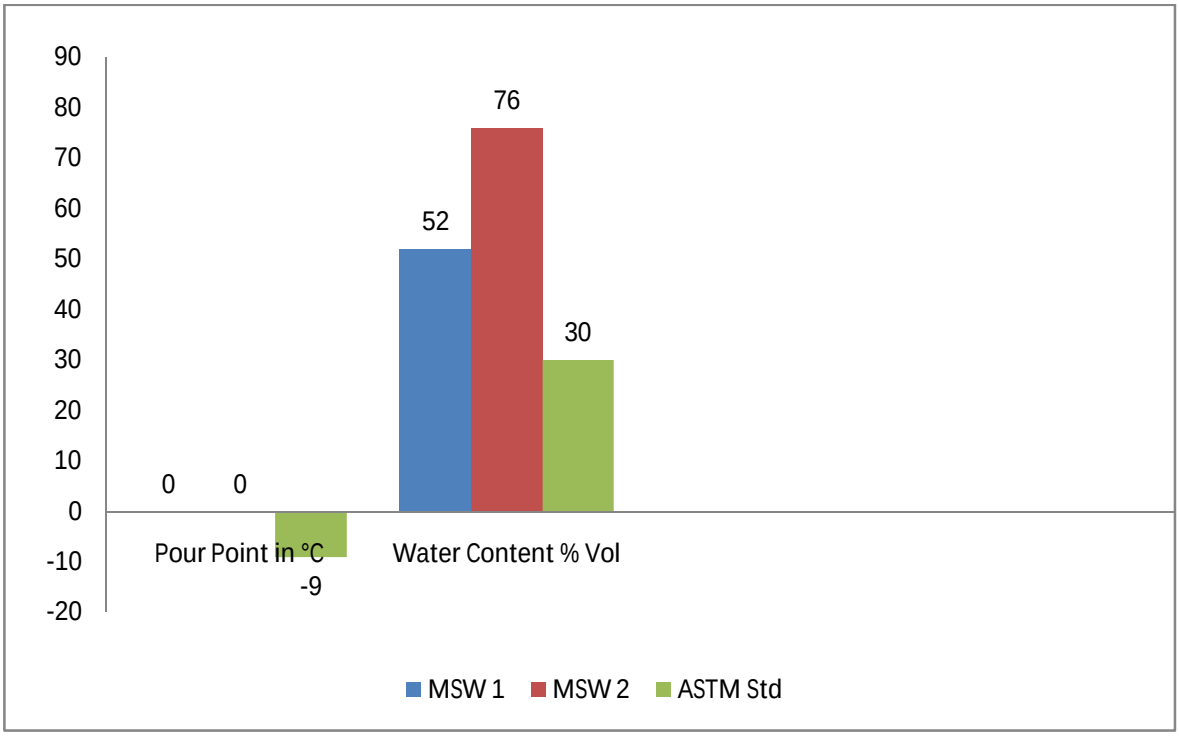

Fig 10 :Comparison of Pour Point and Water content of MSW bio oil with ASTM specification

C. Observations of comparative study with ASTM specifications-

The water content is comparatively higher in bio oil of MSW. Therefore the tests for important parameters like Kinematic Viscosity and Flash point could not be conducted. Before tests to be conducted, the bio oil sample need to be heated to remove the water content present in oil.

It is noted that, there is very little variation in characteristics of two different samples of bio oil of MSW. The characteristics of bio oil are depending upon the feedstock. There will be always variation in percentage contribution of various ingredients in the MSW, though the MSW samples are collected from same location. The quality of bio oil varies with the quality of feedstock.

The sulphur content found in bio oil of MSW is comparatively more than that of ASTM specification. The calorific values are found comparatively lower than that of ASTM standards, but those are likely to be improved if testing would be conducted by removing water content from the bio oil sample.

D. Chemical Characteristics of MSW Bio oil of MSW Sample No 2 –

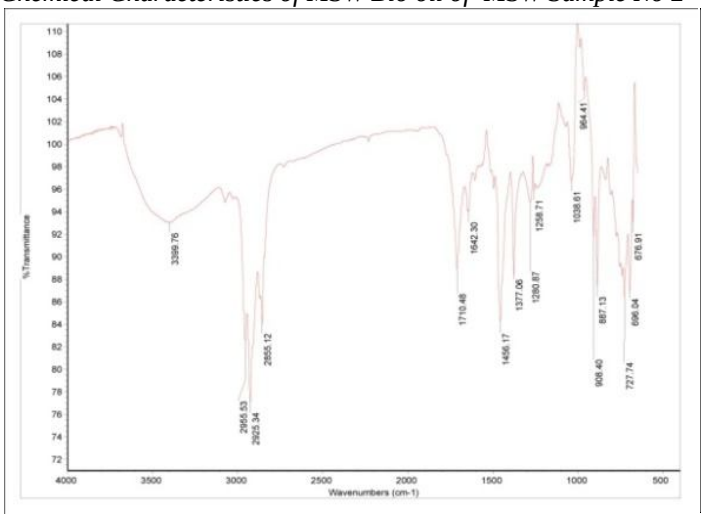

Fig 11 FTIR Spectra of MSW Bio oil

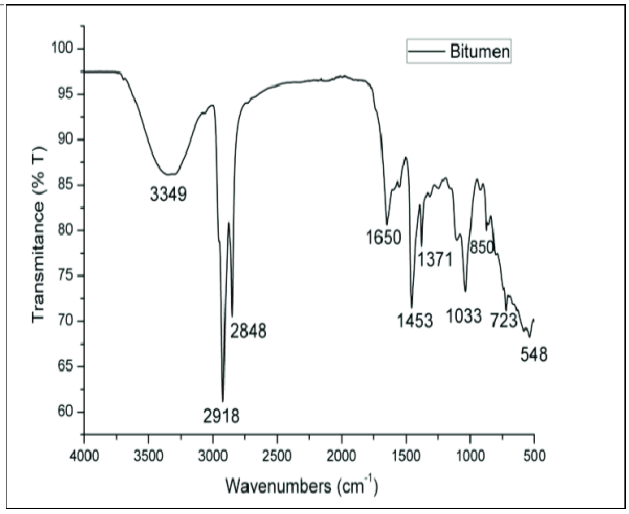

Fig 12. FTIR spectra of Bitumen

The Fourier Transform Infra Red (FTIR) test was conducted . The FTIR spectra of MSW Bio oil shows the group of aliphatic carboxylic acids and aliphatic hydrocarbon groups.(Fig 11) This spectra is matching with the spectra of bitumen. In chemical composition of ashalt or bitumen, these groups are found. Therefore the msw bio oil can be considered as an alternative or partial substitute for asphalt. There is further scope of research to find out the percentage of bio oil that can be used for replacement of bitumen or if any other polymer additives are essential to add in it to meet the properties of asphalt.

V. CONCLUSION

Pyrolysis appears to be an efficient thermo-chemical method to convert the municipal solid waste into bio oil and carbon black. The characteristics of msw bio oil shows interesting results and its comparison with ASTM standards have thrown a light on further line of direction of research. The following conclusions are drawn from this study.

1) Dark brown bio oil is obtained after pyrolysis of municipal solid waste.
2) Due to higher water content present in bio oil of msw, the important characteristics such as kinematic viscosity and flash point could not be conducted. These are the important characteristic to be compared to check the similarity with bitumem.
3) Before pyrolysis, the municipal solid waste shall be heated with the maximum temperature around 60°C to 70°C to remove moisture content. Also the preheatening treatment shall be given to the bio oil obtained.
4) In case of continuous operation of pyrolysis, the heating time of reactor is reduced upto 60 minutes. This will save the energy required for pyrolysis.
5) The calorific values are moderate and might improve after removal of moisture content present in bio oil.
6) The density of msw bio oil found 12% to 13 % less than that of ASTM biofuel minimum standards.
7) The FTIR spectra shows aliphatic carboxylic acids and aliphatic hydrocarbon groups and the peaks are matching with the peaks of FTIR spectra of bitumen. Also these groups are present in chemical composition of bitumen. Therefore the msw bio oil can be considered for partial replacement of bitumen. There is further scope of research in this aspect.
8) Further efforts required to be taken to check the characteristics by processing oven dried msw sample and compare its bio oil with the characteristics of bitumen.

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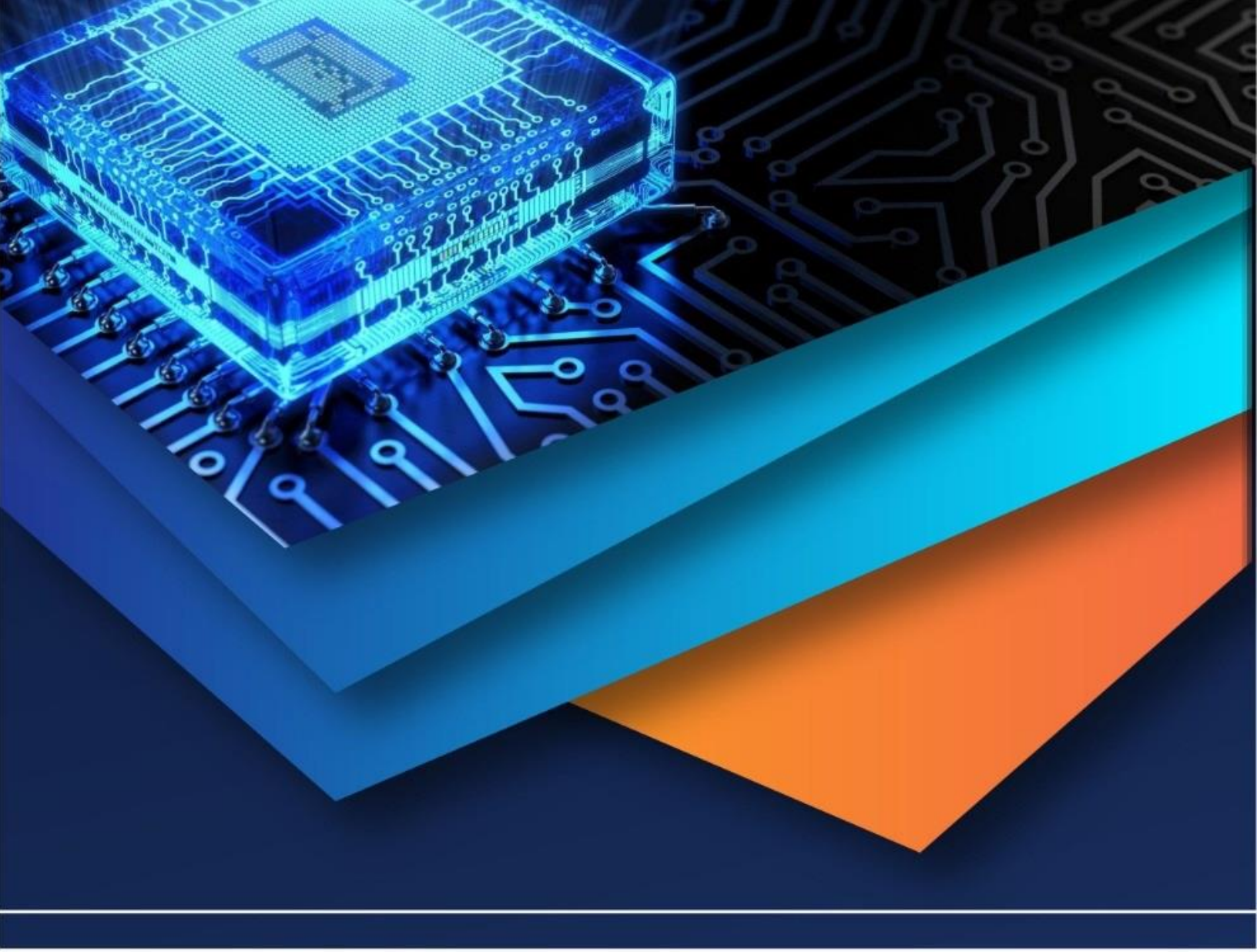

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