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EXPERIMENTAL INVESTIGATION ON EFFECTIVENESS OF ADDING ZEOLITE TOSODIUM BICARBONATE FIRE SUPPRESSANT POWDER

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Abstract
Sodium bicarbonate is commonly used fire suppressant powder because of its high efficiency and low cost. Two main factors affecting the effectiveness of sodium bicarbonate is moisture absorption and cake formation. From the literature survey, it has been found that, by adding small quantities of zeolite particles to sodium bicarbonate the above issues can be eliminated. Also, by adding zeolite the surface area available for each particle increases, which will eventually increase the efficiency. The project aims in experimenting zeolite added sodium bicarbonate fire extinguishing powder and finding out its effectiveness in suppressing. A new type of particulate fire suppressant powder was prepared, in which zeolite of different concentration are added. By the experimental results, it is found that the zeolite added sodium bicarbonate suppressant powder has better performance than the conventional sodium bicarbonate, with relatively shorter extinguishing time and a smaller number of agents required to extinguish the fire. Based on experimental study and mathematical modelling in MATLAB software it is found that the optimum concentration of zeolite in sodium bicarbonate was obtained as 7.939 percentage and extinction time was 1.125 seconds.
Keywords: Sodium bicarbonate, Zeolite, Dry chemical powder, Optimization

1.Introduction
Fire extinguishing powders are noted due to their advantages of high efficiency against fire, cheap cost and environment-friendliness, which are the replacements for halon, that are used in the various fields for fire fighting. For-instance, dry powders could be contained in portable fire extinguishers and can be used in the areas where lack of water supply is present and in tall structure with confounded frameworks. The metal alkali salts have proven specially as efficient fire-suppressants. Potassium bicarbonate and sodium bicarbonate in powder form are the conventional type of fire suppressing agents which are been employed and industrialized in fire suppression for very long time. Even though the metal alkali has the above advantage against fire fighting, It has got unsatisfactory performance against in fire fighting due to larger particle size (10-75 pm), small surface area coverage and shorter residence time when put on the flame. It had found that the productivity of the fine separated solids in smothering flame is a component of the strong surface region which is displayed to the flame.
The particle with larger surface is known to have greater fire suppression ability than that of relatively larger size. But the major constraint in the pressurized container fire extinguisher is that the size of the particle cannot be reduced below a lower limit, because it will leads to the caking of the dry powders and it will be difficult for the particle to penetrate through the fire. In order to override this constraint a new kind of fire extinguishing powder is developed by loading $NaHCO_3$ (sodium bicarbonate) particles on to

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the zeolite matrix. The resultant composite particles obtained after loading sodium bicarbonate in the zeolite matrix is expected to have the characteristics property of the components. The low density property of the zeolite will be acquired by the mixture and this will gives a moderately longer suspending time where as the sodium bicarbonate contribute the mixture to be well dispersed and kept larger surface area presented on to the flame. This results to get a better fire suppression performance for the composite matrix.

2.literature review

Bogdan Boganov et al(2009) presents a brief overview of the zeolite fields of industrial and environmental applications covering the fundamentals and recent developments is proposed. zeolites are used in a variety of applications due to their unique porous properties with a global market of several million tonnes per year. zeolites are majorly used in petrochemical cracking, ion-exchange (water softening and purification), and in the separation of gasses and solvents.

Ming-Hui Feng et al(2016) has conducted experiments to test the extinguishment effectiveness of the water mist derived from various aqueous solutions derive from aqueous solutions containing additives. The results found that the chemical additives improves the suppression efficiency of water mist except for iron sulphate and phosphoric acid. The paper gives the order of suppression efficiency of various aqueous solutions containing chemical additives.

Xiaomin Ni et al(2009) was fabricated a kind of fire suppressing powder with a core shell model ,which has zeolites 13X kept in the space of nano-sized sodium bicarbonate particles. Lab scales experiments shows that the thus prepared nano- composites is given very much high extinction-efficiency as compare to that of the conventional-sodium bi carbonate dry powder which has got very lower extinguishing time and low amount of extinguishing agents are required. The possible fire suppressing mechanism of composite mixture powder is discussed and this involves the mixed functions of sodium bi carbonate and zeolite.

3.identification of suitable chemicals

Based on the literature survey it was observe that addition of small quantity of zeolite powder along with the sodium bicarbonate helps to improve the fire extinction efficiency of $NaHCO_3$.Studies shows that the porous structure and adsorption property of zeolite helps to improve the fire extinction efficiency of sodium bi carbonate. Magnesium carbonate is added to improve the flow property of the powder. Therefore Zeolite and magnesium carbonate is selected as the additives in sodium bicarbonate

Figure.1: Zeolite

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Figure 2: Sodium bi carbonate

4.sample preparation

Preliminary trials experiments are conducted by varying the zeolite concentration. For this 1000 g samples are prepared with different zeolite concentration of 0%,5%,10%,15% etc. To each sample prepared 1% of magnesium carbonate is added to increase the flow property. Sodium bicarbonate is mixed with fixed quantity of Magnesium carbonate and varying amount of zeolite in a beaker containing 1l of distilled water. This solution is stirred for 48hrs in a magnetic stirrer. Then this solution is vacuum freeze dried. Hence obtained white powder was used for conducting the experiments.

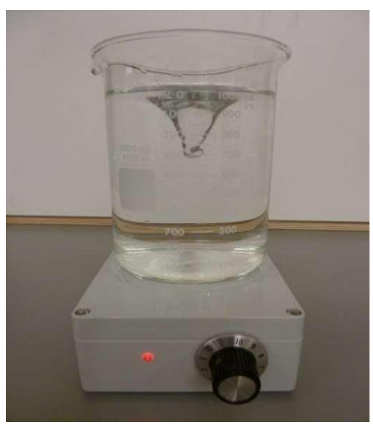

Figure 3: Magnetic Stirrer

Figure 4: Vacuum Freeze Dryer

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Conducting experiments and recording responses

Experiment Setup

- A semi-enclosure space is made and experiments are conducted inside to find out the effectiveness of suppressing pool fire.

The powder container is a stored pressure type fire extinguisher having capacity 1000g.

- The powder-container has an inside diameter 60mm and has a height of 20mm.
- Gasoline is used as the fuel for the experiment.
- Gasoline was kept on the oil-pan having a diameter of 15cm.

Figure 5: Experimental setup

Experiment parameters

- **Amount of powder consumed to extinguish the fire**: Before the experiments was conducted the powder sample with fixed amount is added to the powder container and is pressurized with nitrogen to 20 bar.

Time required to extinguish the fire: A time of 10 sec pre-burning is given before each time, powder

5.results and discussion

Preliminary test results

Primary experiments were conducted on pool fires as explained in chapter 4. The experiments aim to find out the range of zeolite concentration which gives the maximum efficiency.

Table 5.1: Preliminary test results

Zeolite %	NAHCO3 %	MgCO3 %	Initial weight of powder cylinder(g)	Final weight of powder cylinder(g)	Powder used(g)	Time required for fire extinctions
0	99	1	1240.48	1101.08	139.4	2.1
5	94	1	1238.6	1130.95	107.65	1.6

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10	**89**	**1**	**1241.53**	**1148.21**	**93.32**	**1.4**
15	**84**	**1**	**1235.78**	**110913**	**126.65**	**1.9**

Preliminary observations

The experiment results showed that the fire extinction efficiency of sodium bicarbonate initially increases with increase in zeolite concentration and then decreases. The variation extinction time and power consumed according to zeolite composition is represented graphically in Fig 5.1 and Fig 5.2. From these tests it is found that the optimum concentration value of zeolite lies between 5% and 10%. Finally, TGA curves are obtained for the optimum concentration of the new mixture and compared with existing sodium bicarbonate powder and zeolite.

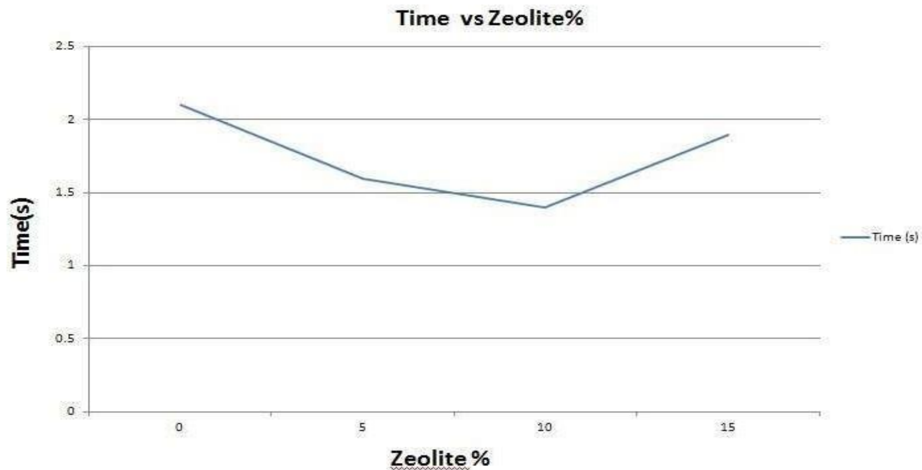

Fig 6 Graph of time require for fire extinction vs zeolite compos

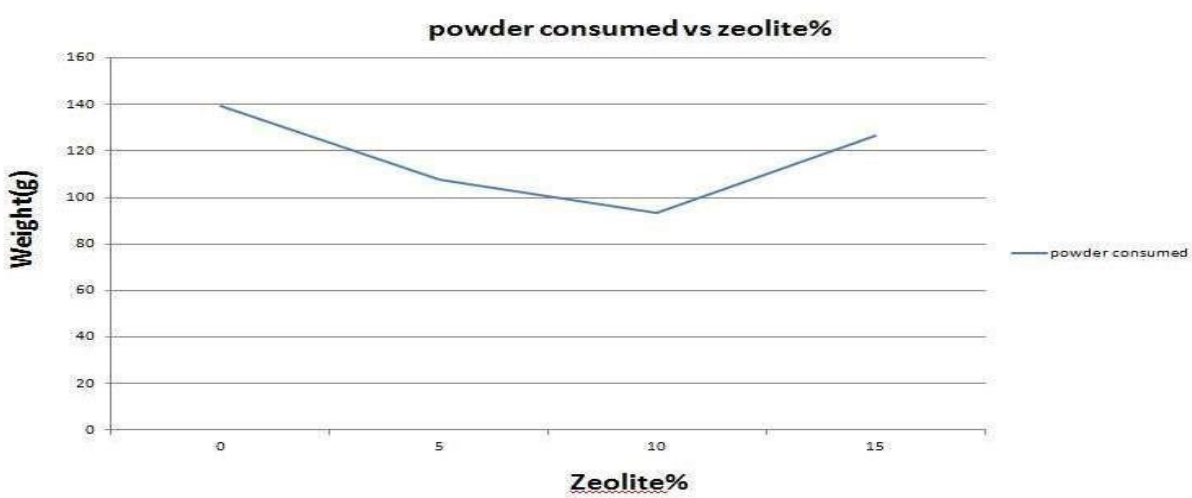

Fig 7 Graph of power consumed vs zeolite composition

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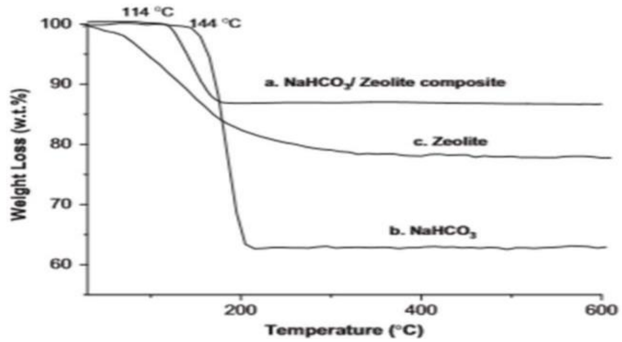

Fig 8. TGA Curves

Development of design matrix

The DOE (design of Experiments) was developed by Taguchi method in the Minitab-16 statistical software. The design-matrix which is chosen for conducting the exp was L9 orthogonal array having 9 experiments. The results of DOE (design of experiments) are given in the below table:

Table 5.2 Design of experiments

Expt No.	Coded units X1	Coded units X2	Zeolite (%) X1	MgCo3 (%) X2
1	1	1	5	0.75
2	1	2	5	1.00
3	1	3	5	1.25
4	2	1	7.5	0.75
5	2	2	7.5	1.00
6	2	3	7.5	1.25
7	3	1	10	0.75
8	3	2	10	1.00
9	3	3	10	1.25

Calculation of regression coifficients and development of mathematical model

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From the preliminary experiment it is found that the optimum concentration value of zeolite lies between 5% and 10%. To find out the optimum concentration 9 different compositions are tested according to Taguchi L9 orthogonal array. The observations of these experiments are listed in the table 5.3.

Table 5.3 fire extinction time for different compositions

Zeolite (%) X1	MgCO3 (%) X2	Powder used (g)	Time (s) Y
5	0.75	112.34	1.7
5	1.00	107.65	1.6
5	1.25	115.82	1.7
7.5	0.75	87.53	1.3
7.5	1.00	73.36	1.1
7.5	1.25	79.94	1.2
10	0.75	96.24	1.5
10	1.00	93.32	1.4
10	1.25	91.48	1.4

The response function representing the time required for extinguishing the fire is expressed as Y = f (X1, X2),
where Y is the time(sec) required, X1 is the percentage of zeolite and X2 is the percentage of magnesium carbonate. The mathematical model to establish the relationships between input and output parameters were developed using Minitab-l6 software at a confidence level of 95%, based on the experimental data collected as per Taguchi L9 orthogonal array. The time required for fire extinction (t) was expressed as a non linear function of process-parameters. The regression equations thus obtained for time as follows:

$Y = 6.067 - 0.8467\,X1 - 3.033\,X2 + 0.05600\,X1^2 + 1.600\,X2^2 - 0.0400\,X1 * X2$

S=0.0372678,

R-sq=98.84%,

R-sq(adj)= 96.91%,

R-sq(pred) = 89.19%

Where (S is the root mean squared deviation, R-sq= Coefficient of correlation)

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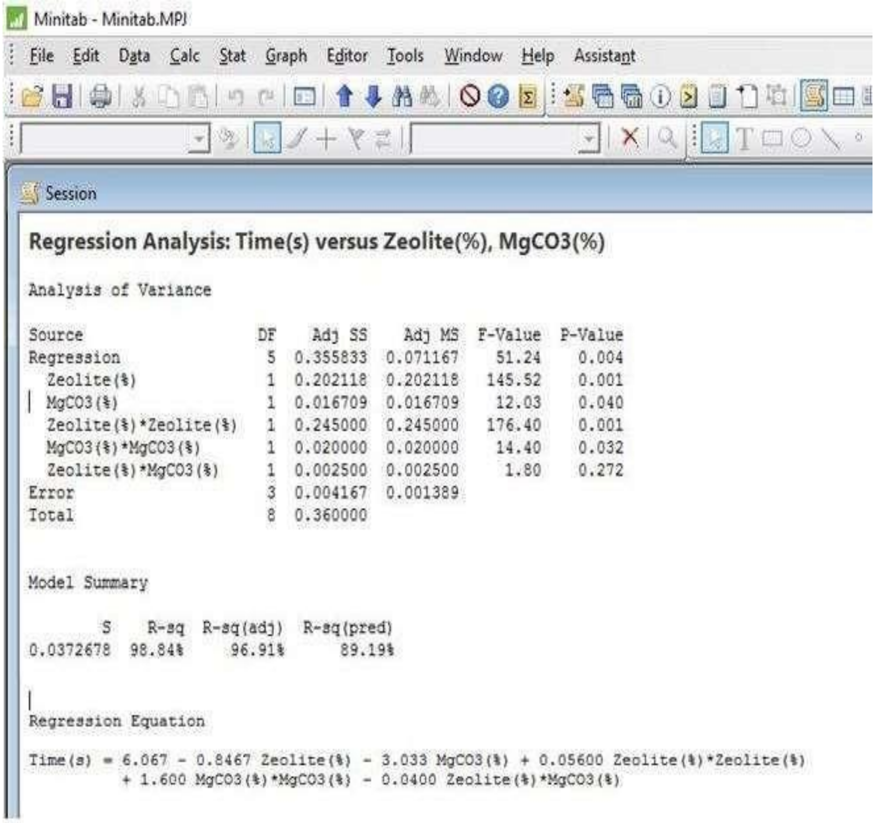
The coefficient of correlation was found to be equal to 0.9884 for time required for extinction. Thus, the model was seen to be statistically adequate to make further predictions. The lack of fit was found to be insignificant. The root mean squared deviation is 0.0372678.



Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.355833	0.071167	51.24	0.004
Zeolite(%)	1	0.202118	0.202118	145.52	0.001
MgCO3(%)	1	0.016709	0.016709	12.03	0.040
Zeolite(%)*Zeolite(%)	1	0.245000	0.245000	176.40	0.001
MgCO3(%)*MgCO3(%)	1	0.020000	0.020000	14.40	0.032
Zeolite(%)*MgCO3(%)	1	0.002500	0.002500	1.80	0.272
Error	3	0.004167	0.001389		
Total	8	0.360000			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0372678	98.84%	96.91%	89.19%

Regression Equation

Time(s) = 6.067 - 0.8467 Zeolite(%) - 3.033 MgCO3(%) + 0.05600 Zeolite(%)*Zeolite(%) + 1.600 MgCO3(%)*MgCO3(%) - 0.0400 Zeolite(%)*MgCO3(%)

Fig 5.4 Minitab window

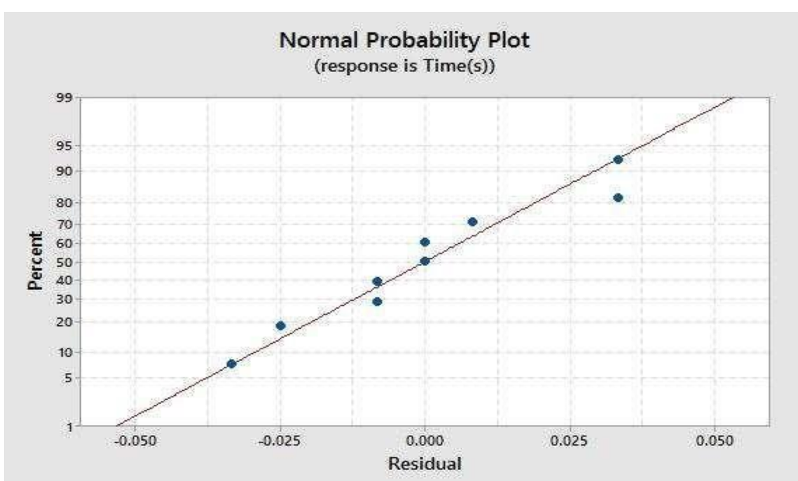


Fig 5.5 Normal-probability plot

One of the assumptions in all the statistical models used in design of experiments is that the experimental errors (residuals) are normally distributed. The normality assumptions can be verified by plotting the residuals on a normal probability paper. If all the residuals fall along a straight line drawn through the plotted points. it is inferred that the residuals/errors follow normal distribution. The normal probability plot obtained for the observed experimental data is given in fig 5.3.

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Checking adequacy of the developed model

The adequacies of the models were tested using the analysis of variance technique (ANOVA) with 95% confidence level. For 95% confidence, the p-value must be less than 0.05. The results of basic ANOVA are presented in Table 5.3. From the results Obtained it is clear that the p-value for the model lies below 0.05. Thus the model can be considered adequate within the confidence limit.

Table 5. Results obtained using Anova

Source		**DF**	**SS**	**MS**	**F**	**P**
Time required	Regression	5	0.355833	0.071167	51.24	0.004
	Residual Error	3	0.004167	0.001389		
	Total	8	0.36			

It is found that the above model is adequate. Each predicted value matches well with its experimental value, as shown in Fig 5.5

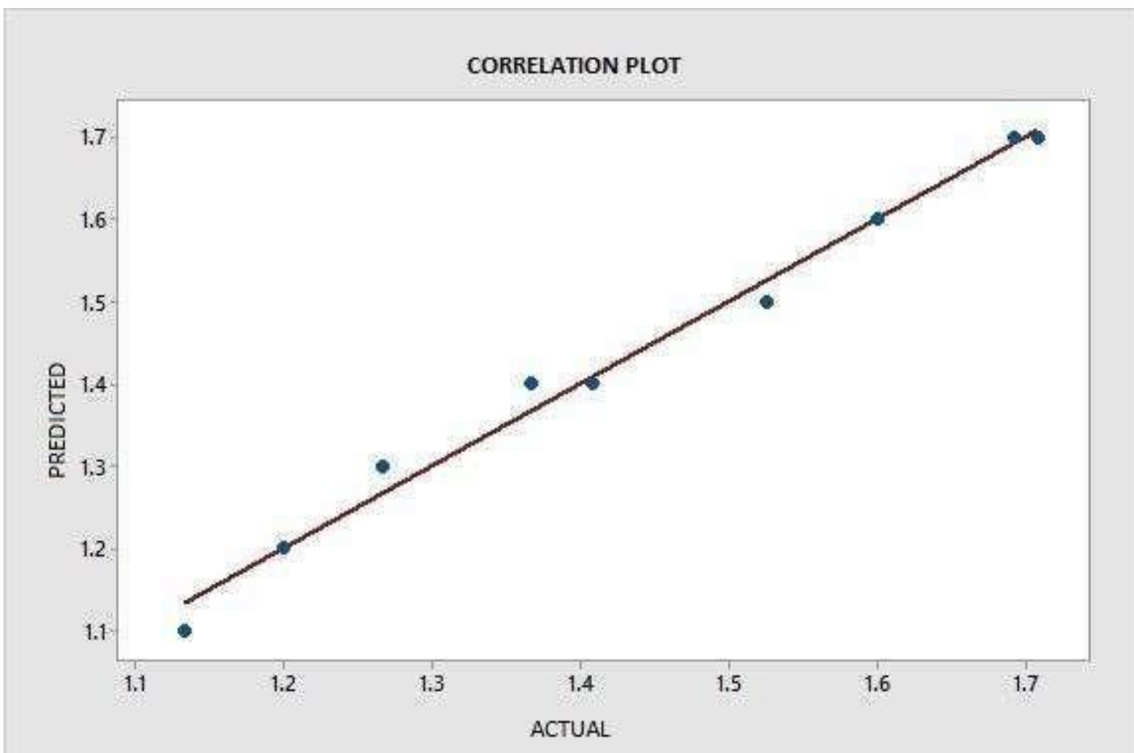

Fig 5.6 Correlation plot

RESULTS OF GA OPTIMIZATION

The genetic algorithm was conducted in the MATLAB and is found that the optimum extinction time is 1.125 seconds with zeolite concentration of 7.939 percentage and magnesium carbonate of 1.041 percentage in the composite mixture

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Table .5 Results of GA optimization

Type	Extinction time (s)	Zeolite (%)	Magnesium carbonate (%)
Single Objective	1.125	7.939	1.041

CONCLUSION

A type of suppressant consisting of sodium bicarbonate particle and zeolite mixed particles was create in with respect the absorbing capacity of porous zeolite. To get the optimum concentration of zeolite for maximum extinction efficiency the experiments were designed according to Taguchi L9 orthogonal array. Using the results, regression analysis was conducted with the help of minitab-17 software, to determine the concentration of zeolite and time required for fire extinction.

A series of experiments for fire extinction-effectiveness indicate that the composite with sodium bicarbonate and zeolite showed superior performance in fire extinction to that of the common dry powers by decreasing the time for extinguishing the fire and the amount in grams of powder consumed. From the experiments it was found that the optimum concentration is in the range of 5-10. Further mathematical modelling using Matlab R2016 revealed that the optimum concentration is 7.939% and minimum time required for extinguishing the fire is 1.125 seconds. Such an improvement of fire-suppression effectiveness indicates the synergetic effect of the sodium bicarbonate particles and sodium ions in the zeolite catching the FFR (flame free radicals), thereby increasing the effectiveness of the fire suppression of dry powder.

From the TG curves its evident that the decomposition of obtained mixture starts early i.e. 114^{o}c rather than pure $NaHCO_3$ which will decompose only at 144^{o}c, which implies the formation of CO_2 will occur early increasing the efficiency of extinguishment.

The fire-suppression effectiveness of the mixture increases due to the greater adsorption ability and low-density property of the zeolite. Zeolite being an adsorbent will make to stick the sodium bicarbonate in to the surface there by larger amount of the sodium bicarbonate available for the fire suppression. Due to the low density, when given into the flame, the composite mixture would breaks more rapidly compared to that of ordinary sodium bicarbonate particle, and react with fire to develop fire inhibiting-species like alkali hydroxides. Mean while, due to the endothermic power decomposition reactions, heat was removed more easily from the flame. Also the water molecules present in the zeolite molecule vaporizes by absorbing heat from surroundings. That will provide a cooling effect to the flame.

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