DEVELOPMENT OF SOFTWARE USING FUZZY LOGIC TO PREDICT EROSIVE WEAR IN SLURRY PIPELINE SYSTEM

Rajat Gupta, Bikramjit Chowdhury, Ambarish Kapil Barpujari, Jnandeep Borbarua

ABSTRACT: The phenomenon of wear is a major challenge in transportation through slurry pipeline system. A predictive software tool has been devised using Fuzzy Logic for predicting the erosive wear rate in slurry pipeline system. It is based on published experimental results conducted in a pot tester for two materials namely brass and mild steel. The software is coded using Java Programming Language.

It has been established that the predictive tool devised works with fair approximation in relation to the experimental results. So it is proposed that this predictive tool can be used in industries as a tool for carrying out predictive maintenance operations in the slurry pipeline system.

Keywords: erosive wear, slurry pipeline system, Fuzzy Logic, Java, software.

I. INTRODUCTION

One of the most exciting aspects of the pipeline industry today is the Freight Pipeline. A freight pipeline is defined as a pipeline whose main purpose is to convey agricultural, mining or industrial products which are in solid form (powdered, granulated, sintered, manufactured, packaged, etc.). Generally, in a pipeline transportation system the loads are moved totally enclosed by their guide way and the motive power is applied via a moving fluid (gas or liquid) which is employed to entrap, fluidize and convey solid cargo through the pipeline.

A generic freight pipeline system has many features which are attractive as well as advantageous. Those may include:

- Traffic reduction
- Air pollution reduction
- Reduced accident
- Reduction in energy consumption
- Very less cost of transportation
- Potential for automation
- Reduction of freight loss and damage

The present work is a lead from the paper by Dr. Rajat Gupta *et al.* [1] where they have studied the parametric dependence of velocity, particle size & solid concentration on the local erosive wear in a horizontal pipeline system. They derived two correlations (1 & 2) for two materials, namely Brass and Mild Steel which relates these parameters to the erosive wear.

$$E_{w_{brass}} = 0.178V^{2.4882}d^{0.291}C_w^{0..516} \quad (1)$$

$$E_{w_{mild\ steel}} = 0.223V^{2.148}d^{0..344}C_w^{0..556} \quad (2)$$

Dr .Rajat Gupta is Professor and Dean (Sponsored Research and Consultancy), National Institute of Technology, Silchar, India.

Bikramjit Chowdhury, Ambarish Kapil Barpujari and Jnandeep Borbarua are pursuing B.Tech from NIT, Sichar.

Considering the fact that the erosive wear is a highly complex & uncertain phenomenon and no universal equation exists that works fine for every situation in industrial applications, thus choosing Fuzzy Logic in this field, which is an approach to handle vagueness or uncertainty, would be an effort to fill the space of desired universal equation Thus taking the two equations as the base of the work, two Fuzzy Inference Systems (FIS) are developed for Brass and Mild Steel which can predict the extent of erosion for a given set of input parameters, namely Velocity, Particle Size & Solid Concentration.

It is seen that the output of the FIS matches with that from the equation within a certain band of uncertainty which is acceptable.

Finally software is coded which acts as a prediction tool and works on Fuzzy Logic. It accepts three input parameters and displays the result. It is seen that output from the software is exactly the same as from FIS which means that the FIS was successfully implemented in the software. It is coded using Java programming language.

Also some future works are suggested in this paper with a view to develop a generic FIS suitable for all materials and also under all environmental conditions.

II. FUZZY LOGIC

The importance of Fuzzy Technologies in engineering is growing as system complexity increases. Fuzzy Logic is a multi-valued type of logic that allows intermediate values to be defined between conventional threshold values. Mathematical models and difference equations generate crisp descriptions of systems. This is fine if the mathematical properties and physical laws of the system are known or can be calculated. However, for non-linear processes, the underlying dynamics of the system can be too difficult, or indeed, impossible to model. In these situations, it is more useful to describe the system as a series of if-then rules. This is essentially what a fuzzy model is. It is a mapping of input space to output space by means of a rule base. Hence, the model requires no strict mathematical equations and the range of uses for the fuzzy model is vast. Fuzzy Inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decision can be made or patterns discerned. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Antonio Cesar [2] developed a new methodology for the study of Flow Accelerated Corrosion phenomenon based on a fuzzy rule system. Gary Brown [3] worked on the prediction of erosion in Tee joints in slurry pipelines using CFD techniques. Hartog *et al* [4] build a knowledge based Fuzzy Model for performance prediction of a rock cutting trencher. Kayacan *et al* [5] used a fuzzy approach for induction hardening parameters selections.

1. Fuzzy Mathematics

1.1 Fuzzy Set Theory

Let X denotes the universal set. The process by which individuals from X are determined to be either members or nonmembers of a set can be defined by a characteristic function. For a given set A, this function assigns a value $\mu_A(x)$ to every $x \in X$ such that,

$$\mu_A(x) = \begin{cases} 1 & ,x \in A \\ 0 & ,x \notin A \end{cases}$$

Thus, the function maps elements of the universal set to the set containing 0 and 1.

This can be indicated by

$$\mu_A(x): \quad X \rightarrow \{0, 1\}.$$

The characteristic function of a crisp set assigns a value of either 0 or 1 to each individual in the universal set. This function can be generalized such that the values assigned to the elements of the universal set fall within a specified range and indicate the membership grade of these elements in the set in question. Thus, large values denote higher degrees of membership and vice versa. Such a function is called a membership function and the set defined by it is a fuzzy set. The membership function μ_A, by which a fuzzy set 'A' is usually defined, has the form

$$\mu_A(x): \quad X \rightarrow [0, 1]$$

where [0, 1] denotes the interval of real numbers from 0 to 1 inclusive of end points. If x_i is an element of universal set and μ_i is its grade of membership in A, then A is written as

$$A = \mu_1/x_1 + \mu_2/x_2 + \ldots\ldots\ldots\ldots + \mu_n/x_n$$

where the / is implied to link the element of A with their grades of membership in A and '+' sign indicates that the listed pair of elements and membership grades collectively form the definition of the set.

1.2Fuzzy rules

A fuzzy rule can be defined as a conditional statement in the form:

IF x is A THEN y is B

where, x and y are linguistic variables and A and B are linguistic values determined by fuzzy sets on the universe of discourse X and Y respectively. An expert's knowledge can be put in the form of various fuzzy sets. These rules are used in fuzzy reasoning. Fuzzy reasoning includes two distinct parts: evaluating the rule antecedent (the IF part of the rule) and implication or applying the result to the consequent (the THEN part of the rule). In classical rule base system, if the rule antecedent is true, then the consequent is also true. In fuzzy systems, where the antecedent is a fuzzy statement, all rules fire to some extent, or in other words they fire partially. If the antecedent is true to some degree of membership, then the consequent is also true to the same degree.

2. Development of FIS

FIS means Fuzzy Inference System. Mamdani type of Fuzzy Inference System is developed for this problem. The basic procedure for building this type of FIS can be explained with the help of a flow diagram as shown in Fig1. The Fuzzy Inference system is a collection of five operations namely, Input fuzzification, Fuzzy Operation, Implication, Aggregation and Defuzzification. After application of these operations the input is mapped to the output.

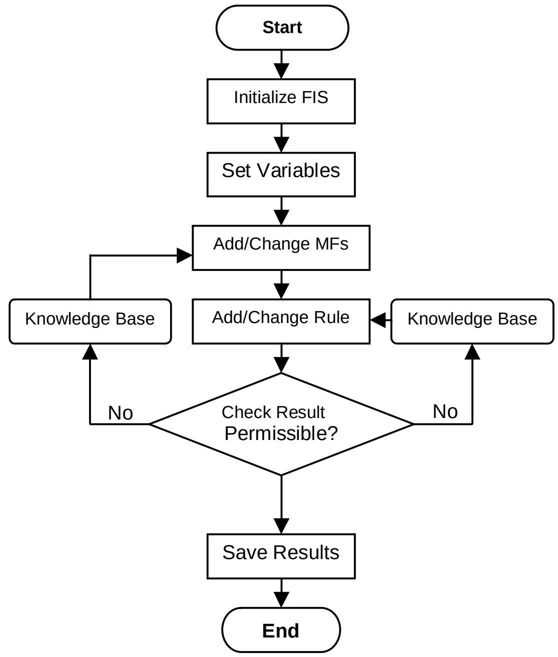

Fig1: FIS Flow Diagram

2.1 Fuzzy Inference System

Based on the above a FIS is build both for Brass and Mild Steel. The variables identified for the problem are:

Table 1: Variables for FIS

Sl. No	Name	Type	Unit	Range	No. of MF
1.	Velocity	Input	m/s	1 – 10	3
2.	Particle Size	Input	µm	10 –500	3
3.	Concentration	Input	%wt	5 – 50	3
4.	Erosion Rate	Output	mm/ yr	~	27

III. ANALYSIS OF RESULTS

1. Quantitative Comparison

The output from the FIS with respect to a set of inputs is compared with that from the equation and experimental results. The objective of this comparison is to determine the percentage variation of the Fuzzy output with respect to the equation output and experimental results as obtained by [1] for both Brass and Mild Steel. While comparing with equation, random values of input variables are generated using equation (3) given by:

$$\text{Random Value} = \text{Lower Range} + \text{Random Number} * \text{Upper Range} \quad (3)$$

where, Random Number is a number between 0 and 1 generated randomly by the compiler.

The % Error is calculated by

$$\% \, Error = \frac{E - F}{E} \times 100 \tag{4}$$

where, E = Equation Output
F = Fuzzy Output

The % variation is the maximum and the minimum % Error determined by equation (4).

1.1 Percentage (%) Variation (Fuzzy Vs Equation)

A plot is made with 100 Fuzzy outputs and 100 equation outputs calculated with 100 sets of values of input variable (v, d & C_w) generated with the help of equation (3). These values of input variables are fed to the FIS and the fuzzy output is obtained. Similarly equation output is obtained. The plot is drawn for both the materials viz, Brass and Mild Steel. It is shown in Fig (2 & 3).

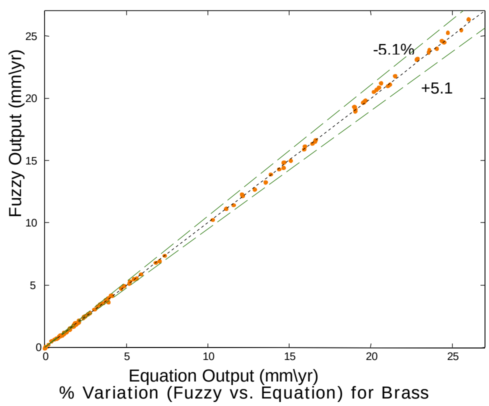

Fig2.

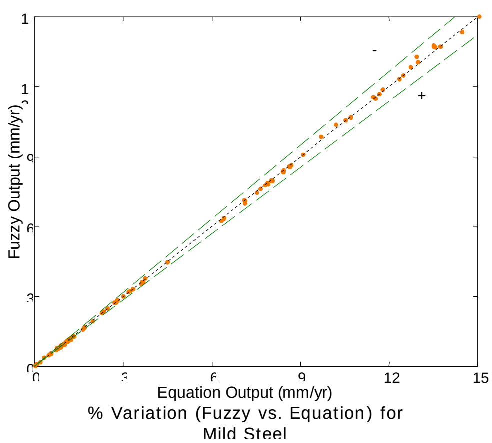

Fig3.

2. Qualitative Comparison

The output from the FIS with respect to each input is plotted and compared with that from the equation.

Fig (4 & 5): Graphs are plotted with Concentration (in % by wt.) along x-axis and Erosion Rate (in mm/yr) along y-axis for three different values of slurry Velocity at constant Particle Size for Brass and Mild Steel respectively.

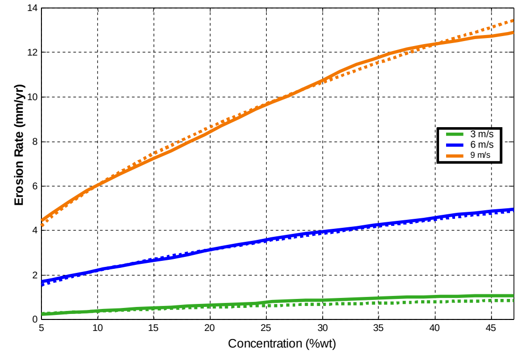

Fig 4

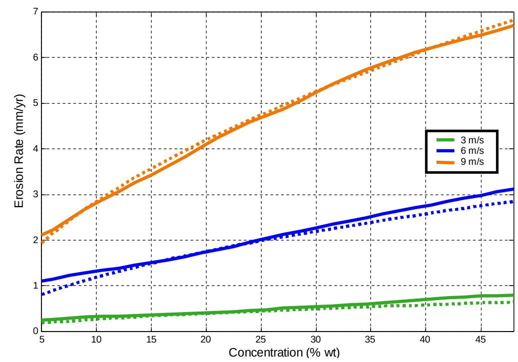

Fig5

Fig (6 & 7): Graphs are plotted with Velocity (in m/s) along x-axis and Erosion Rate (in mm/yr) along y-axis for three different values of Particle size at constant solid Concentration for Brass and Mild Steel respectively.

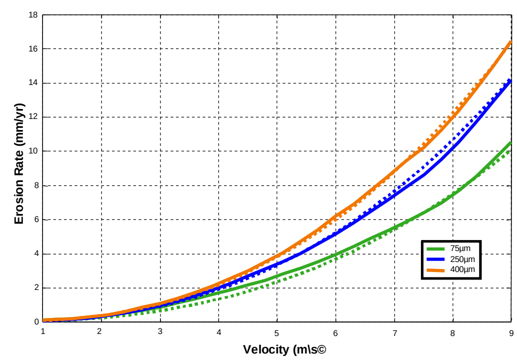

Fig 6

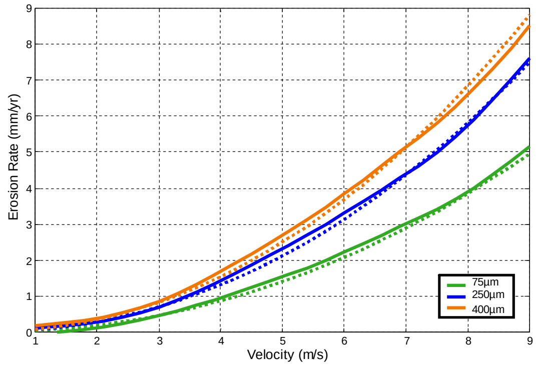

Fig 7

Fig (8 & 9): Graphs are plotted with Particle Size (in µm) along x-axis and Erosion Rate (in mm/yr) along y-axis for three different values of Solid Concentration (in % by wt.) at constant slurry Velocity (in m/s) for Brass and Mild Steel respectively.

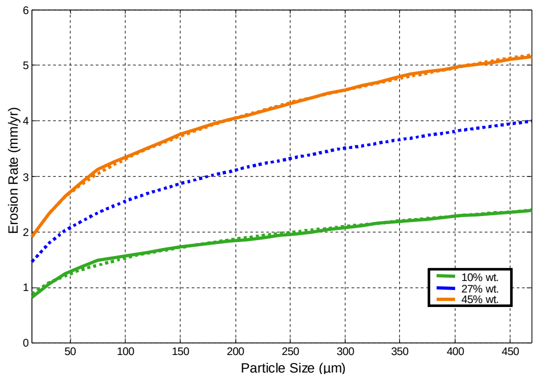

Fig 8

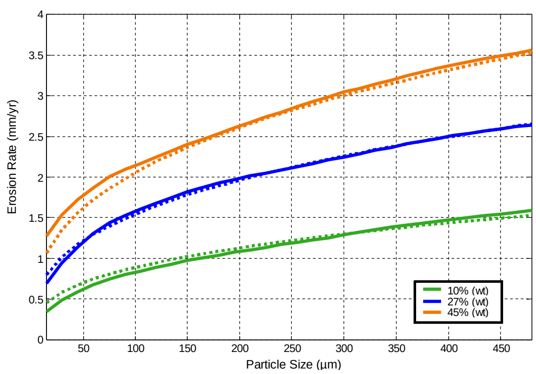

Fig 9

IV.CODING THE SOFTWARE

The software is based on the algorithm shown in Fig 10. The software is built using JDK1.6.0_03.

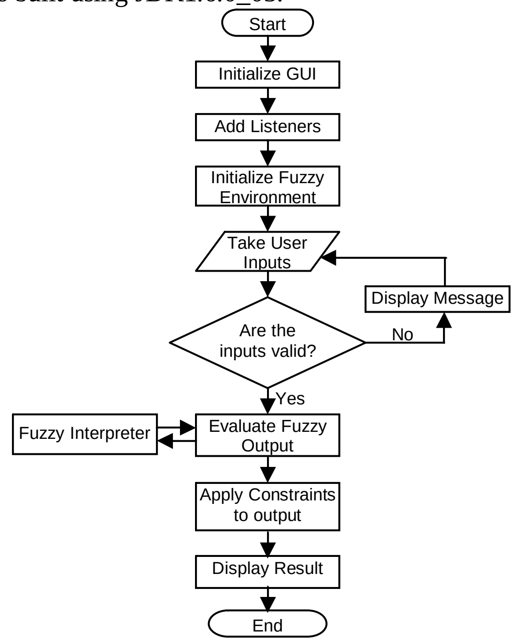

Fig10: Algorithm for Erosion Predictor

1. Comparison

The output from the software for random values of input variables is compared with equation output. Error is found out for each data set using the equation (4). This is done for both the materials namely, Brass and Mild Steel. The results are tabulated in Table 2 & 3.

Table 2: Comparison for Brass (Software vs. Equation)

Velocity (m/s)	Particle Size (µm)	Concentration (% by wt.)	Equation Output (mm/yr)	Software Output (mm/yr)
3.39	343.59	13.19	0.9619	0.9252
4.68	333.35	5.74	1.3832	1.4010
5.63	286.85	29.30	4.8568	4.9607
9.13	485.83	29.37	18.8507	19.2735
6.63	473.13	43.04	10.2660	10.3207
4.82	177.19	45.93	3.6204	3.6394
9.95	299.71	46.93	25.8155	25.9497
4.90	341.59	13.81	2.4531	2.4885
9.03	382.64	46.43	21.6283	21.5942
5.97	177.98	17.06	3.6954	3.7488

The above table shows that the maximum deviation of the Software output is 3.82% and minimum deviation is 0.15% with respect to equation results in case of Brass. The results are approximately within the tolerable limits.

ISBN: 978-960-6766-67-1 ISSN: 1790-2769

Table 3: Comparison for Mild Steel (Software vs. Equation)

Velocity (m/s)	Particle Size (μm)	Concentration (% by wt.)	Equation Output (mm/yr)	Software Output (mm/yr)
2.78	487.46	24.39	0.7160	0.7221
5.25	303.77	38.52	3.0740	3.1590
9.64	148.47	17.09	5.6350	5.7616
7.55	460.96	41.20	8.0356	7.9963
4.31	247.39	27.91	1.5670	1.5263
5.23	248.12	32.51	2.5875	2.6188
4.86	107.36	45.05	1.9838	2.0452
8.06	300.22	33.07	7.0562	7.1137
7.01	460.18	9.00	2.9373	2.8745
2.79	307.22	39.08	0.8041	0.8056

The above table shows that the maximum deviation of the Software output is 3.09% and minimum deviation is 0.49% with respect to equation results in case of Mild Steel. The results are approximately within the tolerable limits.

V. CONCLUSIONS

On the basis of the present investigation and analysis, it can be concluded that the Fuzzy Logic can be used successfully as a tool for the prediction of erosive wear in the case slurry pipeline system using three variables name velocity, particle dimension and slurry concentration. The variation in the software output with respect to equation is within acceptable limits.

- Two Fuzzy Inference Systems have been developed for the prediction of uneven wear for two materials, namely brass and mild steel respectively.
- We can use this FIS to predict the local wear rate in a slurry pipe as long as the concentration and size distribution of the solids across the pipe cross section are known.
- The FIS can be easily implemented into software built specifically as a prediction tool for Wear systems.

This will enable the designer to evaluate the rate of maximum wear at the bottom of pipe to the average wear rate in slurry pipe for any operating conditions. This tool can be used to choose optimum velocity for transportation at any given solids concentration subject to the constraints of pumping cost and life of the slurry pipeline.

VI. FUTURE PROSPECTS

This paper was confined to use of only three factors that influence Erosion Rate, namely Velocity, Particle Size & Solid Concentration. The project can be extended by incorporating other parameters which influence the erosion phenomenon namely, pipe material hardness, angle of impingement, particle hardness, etc. Thus a more generic FIS can be generated which is suitable for any slurry–pipeline combination.

Moreover, the concept of Settling Velocity and Critical Velocity can be incorporated into the system. Since flow conditions are different at different velocities, these concepts can improve the performance of the system.

If not possible all, at least some parameters should be included. Experiments can be performed on Pot Tester to generate data for other Materials. Finally, software can be improved in the sense that the software may work for almost all the top materials suitable for pipeline systems.

VII.NOMENCLATURE

E_w=wear in mm/year
$C_{w=}$ concentration by weight
V=flow velocity, m/s
d=particle dimension (weighted mean diameter)

VIII.REFERENCES

[1]. *Gupta R*, Singh *SN*, *Seshadri V*. Prediction of uneven wear in a slurry pipeline on the basis of measurements in a pot tester. *Wear 1995; 184:169–78*

[2]. *Guimaraes ACF*. A new methodology for the study of FAC phenomenon based on a fuzzy rule system. *Elsevier Ltd; Annals of Nuclear Energy 30 (2003) 853–864*

[3]. *Brown G*. Erosion prediction in slurry pipeline tee joints. *CSIRO (1999) 6-8*

[4]. *Hartog MH, Babuska R, Deketh HJR, Grima MA, Verhoef PNW, Verbruggen HB*. Knowledge based Fuzzy Model for performance prediction of a Rock-Cutting Trencher. *International Journal of Approximate Reasoning 16 (1997) 43-66*

[5]. *Kayacan MC, Colak O*. A fuzzy approach for induction hardening parameters selection. *Elsevier Ltd; Materials and Design 25 (2004) 155–161*

[6]. www.mathworks.com

IX.BIOGRAPHIES

Dr.Rajat Gupta was born on 10th July 1959. He did his B.E from Delhi University and completed his M.Tech in the year in 1986. He has done Ph.D. from Indian Institute of Technology; Delhi in the year 1995. He has been a Professor since 1996. Around 50 papers of his have been published in National/International Journals/Conferences. He is presently holding the post of Dean (Sponsored Research and Consultancy) in N.I.T Sichar.

Bikramjit Chowdhury, Ambarish Kapil Barpujari and Jnandeep Borbarua are students of Mechanical Engineering B.Tech from NIT, Sichar