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Prediction of Gasket Leakage Rate and Sealing Performance Through Fuzzy Logic

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Leakage rate prediction and control are of the utmost importance in most industrial applications for gasketed flanged joints in high-pressure systems, for safety and environmental reasons. In addition, loss of media, and damage to the plant, resulting from leaky joints can be very costly for the industries. Gasket testing and the evaluation of their sealing performance are complex, time-consuming, and costly, and require sophisticated tools capable of predicting leakage based on limited data. In the present work, fuzzy logic is used as a tool to predict the leakage rate and gasket performance of gasketed flanged joints. Different fuzzy models are developed and validated with experimental results for given operating conditions, taking into consideration the gasket type and surface roughness of the mating faces. It is shown that limited experimental test data can be used to build fuzzy models that predict gasket leakage rate and sealing performance.

Keywords: Fuzzy logic; Gasket performance; Gasketed flanged joints; Leakage rate prediction; Limited data points

1. Introduction

The analysis of sealing phenomena and leakage prediction are complex and time consuming, and, to date, most gasket evaluations have been based on a series of lengthy and costly tests. The objective of most tests is to reduce the leakage rate through the system, and therefore to obtain low-leaking joints. Much theoretical and experimental work has been presented on gasket and joint performance evaluation, and the work most relevant to the present work is reported in [1–3]. The later publications presented results on the fuzzy logic application in the evaluation of gasketed flanged joint performance for the selection of the surface roughness of mating faces (platens) [1], and gasket selection [2], that provided the minimum leakage rate for a given system. The complexity of the analysis of the experimental gasket tests, and the associated cost, as well as the existance of many test results in archives, lead to the consideration of a fuzzy decision support system for gasketed flanged joints. Fuzzy logic is a valuable tool for solving complex problems where a mathematical model is not feasible or would be too difficult to obtain. Fuzzy logic can be used to reduce the complexity of existing solutions as well as to increase the accessibility of design parameters and for leakage control. Furthermore, the application of fuzzy set theory, and fuzzy logic in this domain represents a relatively simple and low-cost solution. Once the fuzzy decision support system is developed, gasket leakage rate prediction and system parameter selection for a leak-free joint can be made easily and accurately, at a minimum cost.

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1.1 Fuzzy Logic Rules

Fuzzy logic rules cover a wide range of variables and consider crisp numbers and rules. Fuzzy logic rules are developed in linguistic terms that address the relationship between the inputs and the outputs of a system. The rules are written in the form of *if /then* rules and link the fuzzy set input parameters to their fuzzy set outputs with a set of classical logical "*And*", "*Or*" functions, e.g. [1,2]:

If the helium gas pressure is 400 p.s.i.
and the platen surface roughness is 700 μin
and the stress level on the gasket is S5 (15160 p.s.i.)
then the system leakage rate is very low at 2.2×10^{-6} (mg s^{-1}), [1.00]

where the figure in brackets at the end of the rule represents the rule weight, or the certainty level of the fuzzy rule, which is usually set to 1.0.

Thus, assuming that input parameter pressure is at two levels 1 and 2 (low and high, respectively), the platen surface roughness is at two levels 1 and 2 (20 μin and 900 μin, respectively), the stress level is at five levels S1–S5 and the leakage ranking is from 1 to 32 levels, then by using the Fuzzy-Flou system , such a rule can be presented by numerical values, i.e. "rule number; 1; 1; 5; 32; 1.00". This rule can be read as, from left to right, pressure at low level "1", platen surface roughness at level "1", the gasket stress at level "5", and the resulting leakage value at level "32", with the rule weight being set at [1.00].

2. Present Work

Because of the complexity of gasketed flanged joints and of the leakage phenomena, the experimental time, the number of test points and the associated costs of the experiments, this work presents the results of the fuzzy logic application for the prediction of gasket sealing performance and leakage rate, based on limited experimental runs and test points. It follows the work presented by Arghavani et al. [1–3]. This work provides a fuzzy logic application for gasketed flanged joints. A fuzzy decision support system (FDSS) tool, called Fuzzy-Flou [4], has been used for this purpose. It has been shown that fuzzy logic is a useful and powerful tool that can be applied in the field of gasketed flanged joints, to determine the required sealing parameters for a given system. Fuzzy models are defined based on the results obtained from modified room temperature tightness test (ROTT) procedures with limited test points at constant helium gas pressure [3]. Different fuzzy models are developed based on the test results of different gasket types from the modified ROTT test procedures . The experimental test results from standard "soft" and "standard" ROTT test procedures for similar gasket types are used to validate the fuzzy model prediction. The standard "soft" and "standard" ROTT test procedures comprise 20 test points in three load–unload cycles, with variable gas pressures of 400 p.s.i. and 800 p.s.i., at each point [5]. The difference between the modified and standard ROTT test procedure is the number of test points and gas pressures at the given test points. The "soft" and "standard" test stress levels in the modified and standard ROTT test procedures are presented in [3] and are briefly described in the following section.

This paper presents the results obtained from different fuzzy logic models in the prediction of the leakage rate for specific gaskets and platen surface roughness.

3. Case Study

3.1 Experimental Procedure and Data

The modified ROTT test procedure was designed considering two load and unload cycles of nine test points of different stress levels with constant gas pressures of 200 p.s.i. and 800 p.s.i., at all test points [3]. The test platens used in these experiments were machined by grinding and turning procedures with spiral cuts, having an average surface roughness value of 20 μin and 900 μin[3]. Three types of gasket were used, namely, PTFE sheet, graphite sheet, and spiral wound with graphite filling. Consistency between the experimental data was ensured as the PTFE and the graphite gaskets were cut from the same respective sheets. The PTFE gaskets were cut to the dimensions of inside diameter 4.875 in, and outside diameter 5.875 in, from a sheet 0.064 in thickness. The graphite gaskets were cut to the dimensions of inside diameter 4.875 in, outside diameter 5.875 in, from a sheet 0.062 in thickness. The spiral wound gaskets were made to a standard size having dimensions of $4.75 \times 5.875 \times 0.177$ in^3 [3].

The experiments were performed with modified soft and standard ROTT test procedures with two cycles of nine test points of constant pressure, as presented in Fig. 1. The soft test considers a maximum stress level of up to 10 107 p.s.i., and is used for PTFE gasket types, whereas the standard test considers a maximum stress level of up to 15 160 p.s.i. and is used for graphite and spiral wound types (SW) (Table 1). For the sake of brevity, the experimental data are not presented here, but they can be found in [3]; however, these results are presented in graphical form in the following sections.

As for the soft and standard ROTT test procedures, at each cycle, the stress is increased incrementally, and then decreased to the initial stress level (Table 1). This simulates both the gasket ageing and bolt load relaxation during the service, and perhaps the most important information gained is the sensitivity of the system under investigation to the loss of stress. The stress level at each stress point remains constant until the stabilised leakage rate is measured, then it is incremented or decremented to the next stress level. The helium gas pressure is kept constant during the entire experiment to ensure the elimination of the gas pressure effect at each stress level during the test. Thus, the effect of platen surface characteristics under different stress levels for a given gasket was evaluated [3].

The three types of gasket mentioned above were used with ground finished platens and turned spiral cut finished platens of two levels of roughness, at two levels of helium gas pressure which were kept constant during the entire test. Thus, four experiments were performed on each gasket type, the results of which were used to build one fuzzy model per gasket. Consequently, data from $(3_{gasket} \times 2_{Ra} \times 2_{P(gas)}) = 12$ experimental tests were used to develop the fuzzy models.

3.2 Fuzzy Algorithms and Rules

Using the information provided in [1,2] and the experimental data metioned in Section 3.1 for each type of gasket, fuzzy models and fuzzy rules are developed. Based on the classification model presented in [2], fuzzy algorithms were made for a MISO system (multiple input and single output system fuzzy model) [1]. These algorithms adopted certain criteria

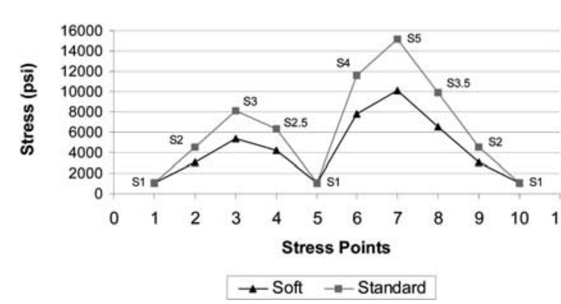

Fig. 1. Two cycles of soft and standard ROTT test stress levels.

Table 1. Two cycles modified (Soft and Standard) ROTT tests stress levels

	Stress levels	Soft stress values		Standard stress values		Gas pressure (p.s.i.)			
		p.s.i.	MPa	p.s.i.	MPa	Test series 1		Test series 2	
						p.s.i.	MPa	p.s.i.	MPa
Cycle 1	S1	1025	7.07	1025	7.07	200	1.38	800	5.52
	S2	3040	20.98	4560	31.46	200	1.38	800	5.52
	S3	5390	37.20	8090	55.82	200	1.38	800	5.52
	S2.5	4220	29.12	6325	43.64	200	1.38	800	5.52
	S1	1025	7.07	1025	7.07	200	1.38	800	5.52
Cycle 2	S1	1025	7.07	1025	7.07	200	1.38	800	5.52
	S4	7750	53.50	11630	80.25	200	1.38	800	5.52
	S5	10107	69.70	15160	104.60	200	1.38	800	5.52
	S3.5	6575	45.37	9860	68.03	200	1.38	800	5.52
	S2	3040	20.98	4560	31.46	200	1.38	800	5.52
	S1	1025	7.07	1025	7.07	200	1.38	800	5.52

and the model comprised of three membership functions, or parameters, in the fuzzy rule premises (input) and one membership function for the associated fuzzy consequence (output). The first series of fuzzy algorithms (knowledge base), does not consider the effect of unloading stress levels in the development of the rules, and was limited to the consideration of the data from the loading section of the two test cycles that are associated with the five stress levels S1, S2, S3, S4, and S5 (Fig. 1).

The membership functions of the premises (also called input parameters of the fuzzy algorithm) were selected as:

1. Helium gas pressure, P (p.s.i.).
2. Platen Surface roughness, Ra (μ*in*).
3. Gasket stress, Sg (p.s.i.).

and the resultant output parameter or consequence is:

System leakage rate, Q (mg s^{-1}).

The levels for each membership function (parameter) are defined as:

1. Gas pressure is at two levels 200 and 800 p.s.i., as low and high pressure, respectively.
2. Platen surface roughness is at two levels 20 and 900 μin.
3. Gasket stress is at five levels S1, S2, S3, S4, and S5, where the highest number represents the highest stress level. The associated stress values for each stress level are set based on the values presented in Table 1. The soft values are considered for PTFE gaskets, and the standard values for graphite and SW gaskets.
4. Leakage rate levels for: (*a*) PTFE gasket is at 18 levels, (*b*) graphite is at 18 levels, and (*c*) spiral wound is at 17 levels.

Thus, based on the algorithm presented above, with three input parameters (premises membership functions) at 2, 2, and 5 levels and one consequence regardless of its level, a minimum of $2 \times 2 \times 5 = 20$ rules can be defined.

Based on this information, the algorithms for the three types of gasket (PTFE, graphite, and SW) are developed following [1] and [2]. The graphical representation of the fuzzy algorithms described above, obtained from the Fuzzy-Flou software [4], is presented in Fig. 2, for PTFE gaskets, showing the premises, the consequence, and the rules. The graphical representation for the two other types of gasket remains the same and it is not repeated here.

3.3 Modified Fuzzy Algorithms and Rules

The fuzzy rules of the algorithms presented in Section 3.2 and Fig. 2, were modified to incorporate the experimental data from the unloading parts of the two test cycles, since the earlier fuzzy algorithms did not consider the leakage rates resulting from the unload stress levels. The stress levels in the unloading part of cycles one and two were S1, S2.5, S3.5, shown in Table 1. However, in order to incorporate the data from the load and unload sections of cycles one and two in the fuzzy algorithms and the fuzzy rules, it is necessary to consider the data for S1, S2, S3, S4, and S5 stress levels. Therefore, the leakage values for stress levels S2, S3, and S4 at the unloading parts B were determined by a two- and three-point Lagrangian interpolation formula. The two-point Lagrangian formula is:

$$y = \left\{\frac{x - x_2}{x_1 - x_2}\right\} y_1 + \left\{\frac{x - x_1}{x_2 - x_1}\right\}, y_2$$

and it can be rearranged as:

$$y = y_1 + \left(\frac{x - x_1}{x_2 - x_1}\right)(y_2 - y_1)$$

The three-point Lagrangian formula can be written as:

$$y = k_1 y_1 + k_2 y_2 + k_3 y_3$$

$$\textit{where } k_1 = \left(\frac{x - x_2}{x_1 - x_2}\right)\left(\frac{x - x_3}{x_1 - x_3}\right), \textit{etc.}$$

As a result, an additional input parameter at two levels of load and unload was added to the algorithms. The levels of member-

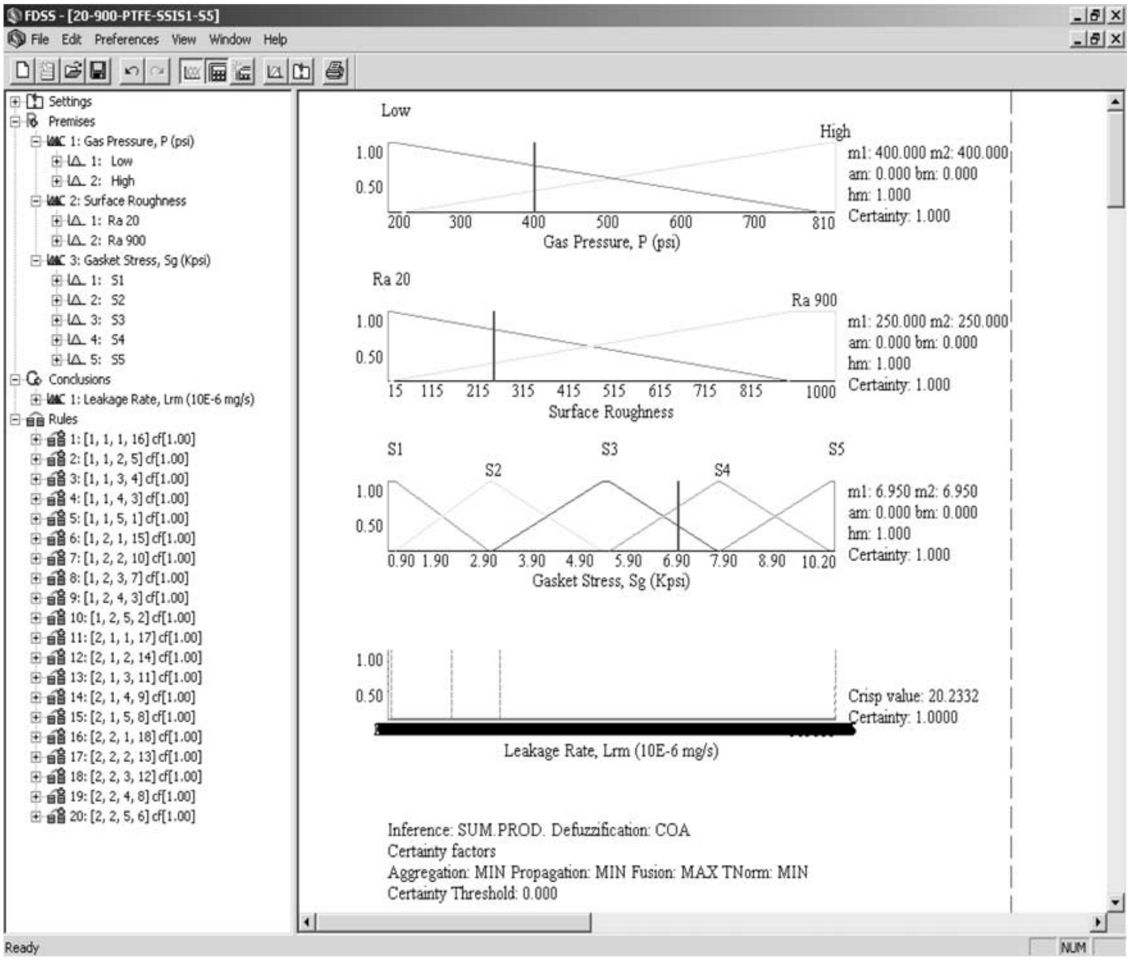

Fig. 2. A fuzzy algorithm for a PTFE gasket, considering the load effect on the leakage rate only. Predicting the leakage rate for the PTFE gasket at gas prressure 400 p.s.i., platen surface roughness Ra = 240 μin, and gasket stress 6950 p.s.i.

ship function for the gas pressure, platen surface roughness, and stress levels remain the same, at two (2), two (2) and five (5) levels, respectively, as in the previous algorithm, whereas for each gasket type, the level of the membership function "leakage rate" is modified. Consequently, considering the load and unload data of the two cycle tests, presented earlier, the leakage rate levels for: (*a*) PTFE gasket was modified to 32 levels, *b*) graphite was modified to 31 levels, and (*c*) spiral wound was modified to 30 levels.

Thus, the modified fuzzy algorithm is of the form MISO (multiple input and single output) with four input parameters and one output parameter. The membership functions (parameters) for the modified fuzzy algorithms are:

1. Helium gas pressure, P (p.s.i.).
2. Platens surface roughness, Ra (μin).
3. Load–unload, LU.
4. Gasket stress, Sg (p.s.i.).

and the resultant output parameter is:

System leakage rate, Q (mg s^{-1})

Based on this algorithm with four input parameters (premises membership function) at (P) 2, (Ra) 2, (LU), 2 and (Sg) 5 levels and one consequence at (Q) 32, 31, and 30 levels for PTFE, graphite and SW gaskets, respectively, a minimum of $2 \times 2 \times 2 \times 5 = 40$ rules were defined, for each gasket type. Note that the membership function level of consequence does not affect the number of rules.

The information given above is used to present three modified algorithms for the three types of gasket PTFE, graphite, and SW. The graphical representation of the fuzzy algorithms described above, obtained from the Fuzzy-Flou software [4], is presented in Fig. 3, for a PTFE gasket. The graphical representations of algorithms for the three types of gasket remain the same, as shown in Fig. 3, except for their rules. Thus, this representation is not repeated for the other two gasket types. The algorithm takes into consideration the effect of loading and unloading on the leakage rate, in the development of the fuzzy rules, following [1] and [2].

3.4 Fuzzy Models Validation and Leakage Prediction

In order to validate and determine the capability of the developed fuzzy models presented in Sections 3.2 and 3.3,

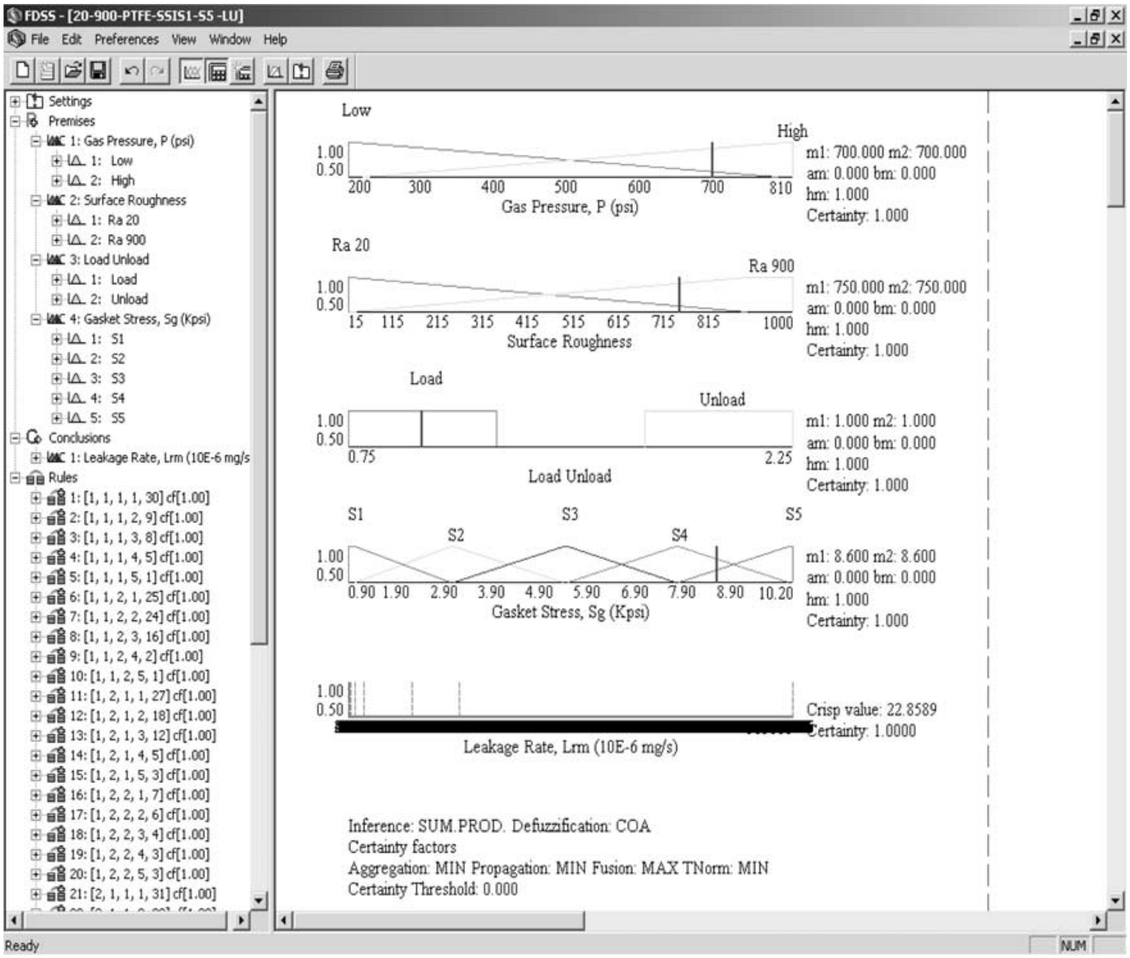

Fig. 3. A fuzzy algorithm for a PTFE gasket, considering the load and unload effect on the leakage rate. Predicting the leakage rate for the PTFE gasket at gas pressure 700 p.s.i., platen surface roughness Ra = 750 μin, and load section stress 8600 p.s.i.

experimental test results for similar gasket types with platens of different surface roughness were used. For each algorithm, based on the gasket type, the experimental results of the ROTT test on the PTFE, graphite, and spiral wound gaskets, as defined in the earlier sections, were considered. These tests were performed based on the soft and the standard ROTT test procedures, using platens of spiral cut finish form with an average arithmetic surface roughness value of 250 μin. Each experimental test comprised three load and unload cycles of 20 test points, with the gas pressure being switched at each stress level from 400 to 800 p.s.i.

The graphical representation of these experimental results indicates and compares the existing variation from test to test, and compares the results obtained from their associated fuzzy models. The experimental and the fuzzy results are presented in the following sections.

3.5 PTFE Experimental Results for Fuzzy Validation

The results of the experimental tests to validate the fuzzy models of the PTFE gasket were obtained based on standard soft ROTT test procedures, which comprised 20 test points in three load and unload cycles, with variable helium gas pressures at certain stress levels. The platens used were produced by spiral cut finish turning with a surface roughness of 250 μin. Three experimental tests indicated by Exp1, Exp2, or Exp3, are used for comparison with the results obtained from the fuzzy decision support system (FDSS). The leakage results from the experiment and those obtained from the fuzzy models are presented in Figs 4 and 5. The results in Fig. 4 are from the fuzzy model that considers only the effect of loading stress on the leakage rate. That explains why the leakage rate results obtained do not correspond to the experimental results at the low stress level, S1 (refer to Table 1 for definition). A shift in the leakage rate in fuzzy results can be seen. This is due to the fact that the data used to develop the fuzzy models are from a Gylon PTFE gasket of $\frac{1}{2}$ in width, with platens III1 of Ra = 20 μin and I1 of Ra = 900 μin, a surface finish that produced a greater leakage rate at higher stress levels compared to the experimental results obtained from a PTFE gasket of $\frac{3}{4}$ in width, with platens of Ra = 250 μin. Also, as has been indicated in [3] the effect of surface roughness on the leakage rate of the PTFE gasket was not evident, and cannot be

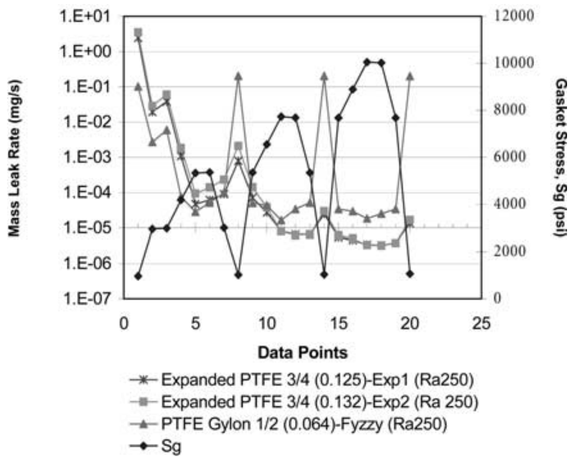

Fig. 4. Experimental and fuzzy leak results for the PTFE gasket, with platen surface roughness at *Ra* = 250 μin. The unloading effect has not been considered in the fuzzy model.

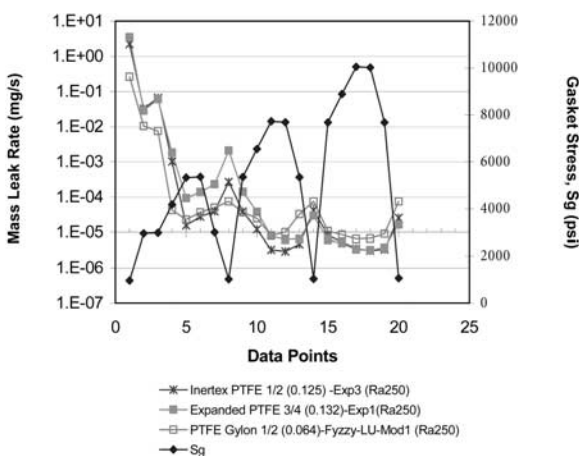

Fig. 5. Experimental and fuzzy results for the PTFE gasket, with platen surface roughness at *Ra* = 240 μin. The fuzzy model considers the load and unload stress effect.

evaluated properly. Furthermore, the leakage results obtained vary slightly from test to test, and are not always repeatable. Thus, these factors add to the complexity involved in the PTFE gasket performance evaluation and leakage prediction.

To improve the leakage prediction of the fuzzy models presented in the earlier section, the effect of stress levels on the leakage rate at both load and unload (*LU*) sections, was considered in the new algorithm. However, such an algorithm did not eliminate the overshoot values at the S1 stress levels. This is because when testing a PTFE gasket, at low stress levels, platens with smooth surface finish e.g. having a ground surface produce a higher leakage rate compared with the rate for a turned surface with circumferential grooves and edges. Thus, such results also affect the outcomes of the other rules and provide slightly higher leakage rates. The *Ra* = 250 finish of the spiral cut turned surface falls within the category of platens with a surface finish of *Ra* = 900, and experiments have shown that it produces lower leakage rate. Therefore, the fuzzy ranking values of the leakage rate, for the fuzzy model were retuned to incorporate such knowledge. Consequently, based on other existing experimental data and experience, the fuzzy rankings in these fuzzy rules were retuned to consider lower leakage values at higher stress levels. Such modifications improved the fuzzy prediction, as values closer to the experimental results were obtained, and are presented in Fig. 5.

The fuzzy models developed were also used to predict the leakage rate for a PTFE gasket type at a pressure of 200 (p.s.i.), with platens I3 *Ra* = 700, and I1 *Ra* = 900, for the modified soft ROTT test at two cycles. The fuzzy leak results obtained are compared with those obtained from the experiments presented in Fig. 6. The fuzzy results obtained correspond to those from the experiments. The fuzzy models developed for the PTFE gasket can be used to predict the leakage rate for a system at gas pressures between 200 and 800 (p.s.i.), with platens of turned surface form with surface roughness in the range 20–1000 μin, and gasket stress levels of 0.900–10.10 Kp.s.i.

The results indicate that by considering the existing experimental data combined with experience and expert knowledge, the fuzzy algorithms (knowledge base) can be improved to predict real situations, where the leakage phenomena become more complex, as in the case of a PTFE gasket type.

3.7 Graphite Gasket Experimental Results for Fuzzy Validation

The experimental test results used to validate the fuzzy models of the graphite gasket were obtained based on standard ROTT test procedure, which is comprised of 20 test points in three load and unload cycles . Results of two experimental test indicated by Exp1 and Exp2, are used for the evaluation and comparison with the results obtained from the FDSS, under the same operating conditions. The leakage results from the experiment and those obtained from the fuzzy algorithms are presented in Figs 7 and 8. The results presented in Fig. 7 are from the fuzzy model that considers only the effect of loading stress on the leakage rate. That explains why the results

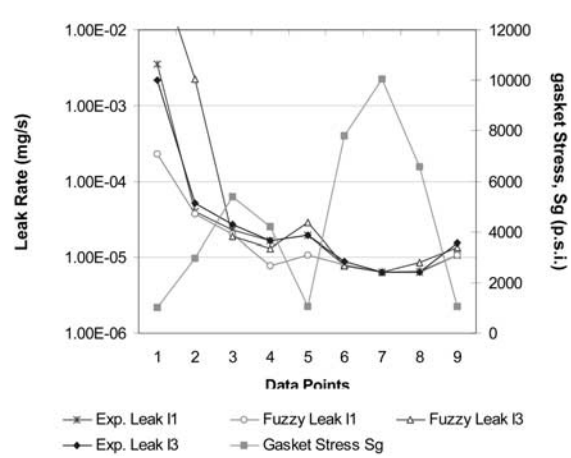

Fig. 6. Experimental and fuzzy results for the PTFE gasket, with platens I3 and I1, at gas pressure 200 p.s.i. for two test cycles.

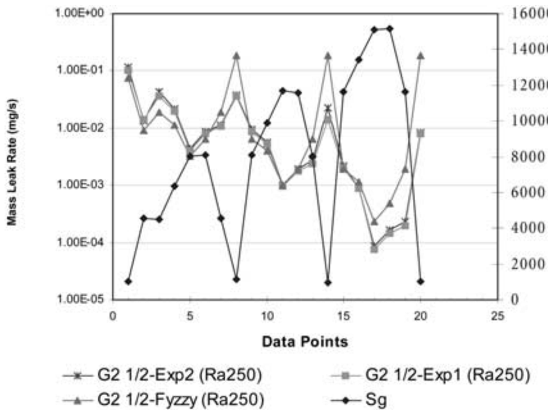

Fig. 7. Experimental and fuzzy leakage results for the graphite gasket, with platen surface roughness *Ra* = 250 μin. The fuzzy model considers only the effect of loading stress on the leakage rate.

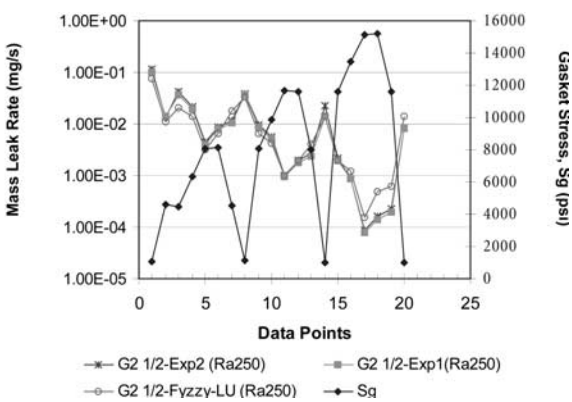

Fig. 8. Experimental and fuzzy results for the graphite gasket, with platen surface roughness *Ra* = 250 μin. The fuzzy model considers the load and unload (*LU*) effect on the leakage rate.

obtained from this fuzzy model do not correspond with the experimental results, at the lower stress level, S1 (refer to Table 1 for definition). However, in general, this fuzzy model predicts the leakage results very well and simulates the results obtained from the real situation. A shift in the leakage rate of the fuzzy results can be seen. The effect of surface characteristics on the leakage rate of the graphite gasket types was discussed by Arghavani et al. [3], i.e. for a particular surface form, the surface roughness effect is more evident on the sealing performance and the leakage rate of such a gasket.

To enhance the performance of the fuzzy models for a better prediction, the fuzzy rules in the latter model were modified to take into consideration the effect of stress levels on the leakage rate at load and unload (*LU*) sections. The results obtained from the refined fuzzy model are presented in Fig. 8. It can be seen that the retuned fuzzy rules in this algorithm provide results in which the overshoot values at the S1 stress levels are eliminated. The results obtained correspond well with the results obtained from the experiments.

The latter fuzzy model developed was also used to predict the leakage rate for the graphite gasket type at a pressure of 800 (p.s.i.), with platens I3 *Ra* = 700, and I1 *Ra* = 900. The fuzzy leakage results obtained are compared with those obtained from the experiments in Fig. 9. It can be seen that the results obtained closely correspond to the experimental results. The fuzzy model developed for the graphite gasket can be used to predict the leakage rate of the above-mentioned gaskets, for the range of gas pressure of 200–800 p.s.i., for platens of turned surface form with a surface roughness ranging of 20–1000 μin, and for gasket stress levels 0.900–15.150 Kp.s.i..

3.8 Spiral Wound Experimental Results for Fuzzy Validation

The experimental test results used to validate the fuzzy models for a spiral wound gasket are indicated by Exp1 and Exp2 and are obtained based on the standard ROTT test procedure [5], which is comprised of 20 test points for three load and unload cycles, with a varying gas pressure of 400 and 800 p.s.i. at certain stress levels. The platens used in these tests are of spiral cut finish with a surface roughness of 250 μin. The fuzzy models were developed based on a modified standard ROTT test procedure with a limited number of test points, in two cycles of load and unload stress levels, with constant helium gas pressures of 200 and 800 p.s.i., during the entire test. The leakage rate is obtained from the corresponding fuzzy models, for a roughness of 250 μin. The fuzzy leakage results obtained from the model, simulating the experimental results, and the leakage rate from the experimental tests are presented in Figs 10–12. Please note that in Fig. 10, the leakage rate results for SW-Exp1, at higher stress levels, corresponding to the data points 17–19 are the results of system recording error. These results should be almost equivalent to the leakage rate results obtained for SW-Exp2.

The fuzzy leakage results presented in Fig. 10 are from the fuzzy model that considers only the effect of loading stress on the leakage rate, in the modelling of the fuzzy rules. Nonetheless, the results obtained fairly predict the experimental results. While the fuzzy models predict accurately the results obtained

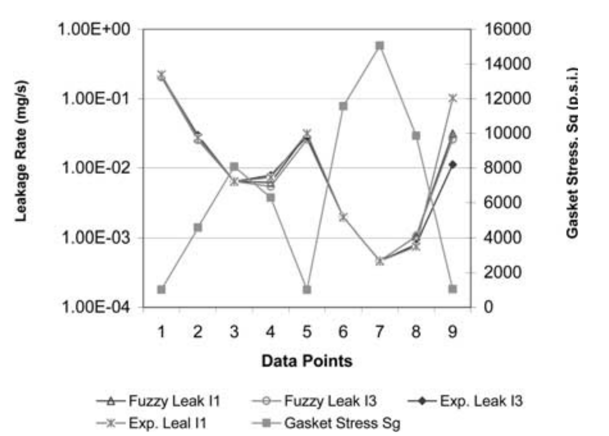

Fig. 9. Experimental and fuzzy results for the graphite gasket, predicting the leakage rate for platens I3 and I1, at gas pressure 800 p.s.i., for two test cycles.

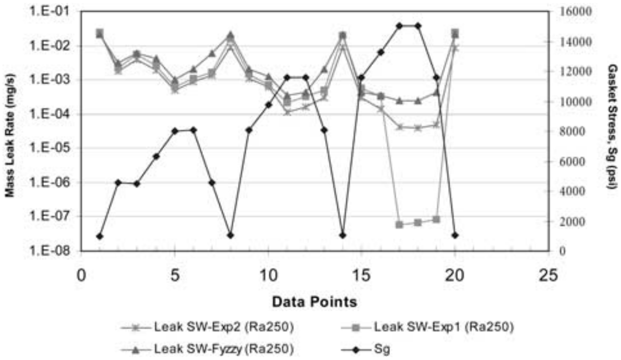

Fig. 10. Experimental and fuzzy results for the SW gasket. The fuzzy model considers the effect of load stress levels on the leakage rate only.

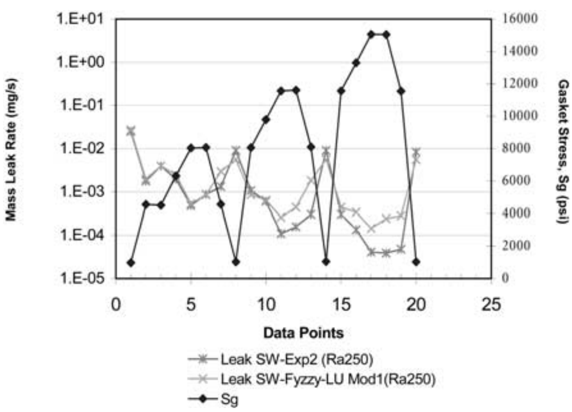

Fig. 11. Experimental and fuzzy results for the SW gasket, using the standard ROTT test, with platens fo rsurface roughness Ra = 250 μin.

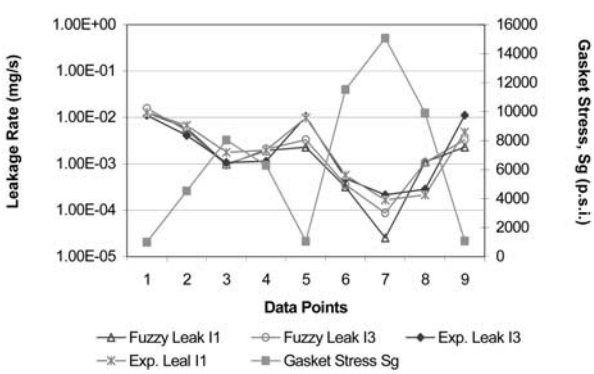

Fig. 12. Experimental and fuzzy results for the SW gasket, predicting the leakage rate for platens I3 and I1, at gas pressure 800 p.s.i., for two cycles of the modified standard ROTT test.

from the real situation, a slight shift in the fuzzy results of the leakage rate at higher stress levels can be seen. This is perhaps due to the fact that ground finish platens III1 produce a higher leakage rate compared with platens produced with a turning procedure [3], thus influencing the result of the fuzzy system.

Thus, to improve the performance of the fuzzy models for better prediction, the fuzzy rules in the latter model were modified to take into consideration the effect of stress levels on the leakage rate at load and unload (*LU*) sections. However, no major improvement is noticed, and this is perhaps because the leakage data from the load and unload sections, used to modify the fuzzy models, were more or less the same.

The expert knowledge gained can be incorporated into the fuzzy algorithms (knowlege base) for further improvement. The ranking values in the fuzzy rules of the last fuzzy algorithm (load–unload) were retuned, using expert knowledge. As a result some improvement was observed in the results obtained from the fuzzy model that corresponded better to the real situations. The fuzzy results of the modified algorithms are presented in Fig. 11.

The developed fuzzy model was also used to predict the leakage rate for the spiral wound (SW) type gasket with platens of I3 Ra = 700, and I1 Ra = 900, at a helium gas pressure 800 p.s.i.. The fuzzy leakage results obtained are compared with those obtained from the experiments in Figure 12. It can be seen that the fuzzy model produces leakage rate results that correspond closely to the results obtained from the experiments. The fuzzy model developed for the SW gasket can be used to predict effectively the leakage rate for said gasket, for a range of gas pressures of 200–800 p.s.i., with platens of turned surface form with surface roughness ranging of 20–1000 μin, and gasket stress levels of 0.900–15.150 Kp.s.i..

4. Conclusions

Gasket testing and sealing performance evaluation is complex, time-consuming, and costly requiring sophisticated tools capable of prediction based on existing and limited data. This paper presented a fuzzy logic application for the sealing performance and leakage rate prediction of gasketed flanged joints based on limited experimental results and limited test points. Different fuzzy models were developed and validated with experimental results for given operating conditions, considering the gasket type and platen surface roughness. Fuzzy logic models and their associated fuzzy rules are defined based on the results obtained from the modified (soft and standard) ROTT tests procedures with limited test points. Fuzzy models and rules were further modified, by considering additional factors in the models and using expert knowledge input, for better prediction and more accurate results. Fuzzy models were validated using the "soft" and "standard" ROTT test experimental results, and the results obtained are presented in graphical form. The results indicate that the fuzzy models developed with limited experimental test data are capable of predicting gasket sealing performance based on the leakage rate, with great accuracy. The fuzzy prediction results presented in this work indicate that fuzzy logic has a great potential for application in the field of gasketed bolted flanged joints for solving complex phenomena such as leakage rate, where mathematical models are not feasible and are too complex to develop. The fuzzy logic approach in this domain will reduce experimental runs, test points, and time, and ultimately reduce associated costs.

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