1999-01-3619

Investigation on the Role of Gasketing Materials In Foaming of Lubricating Oils

Alan L. Freiberg
Dow Corning Corporation

Theodore W. Selby
Savant, Inc.

ABSTRACT

Foaming of lubricating oil during operation of any automotive mechanism is undesirable. To control this problem, anti-foaming additives are often part of the formulated oil. However, during use, the oil contacts the gasketing material used to seal the mechanism and may extract pro-foamants in sufficient quantity to overwhelm the anti-foamant additive.

Recognition of this problem has led to several different in-house tests of oil/gasket compatibility seemingly giving divergent information and technical direction concerning correction of foam-inducing factors of both the oil and gasket.

It seemed appropriate to investigate and quantify the relative importance of several of the presumed influences on oil/gasket interaction. To do this, a relatively simple test simulating oil/gasket contact in the operating mechanism has been developed around an air foam-bath and applied in a series of Taguchi matrix studies to determine the influential factors.

INTRODUCTION

Any tendency of a lubricating oil or hydraulic fluid to foam in service is considered highly undesirable. Such foaming can severely affect the performance of a lubricating oil and jeopardize the life of the mechanism in which the oil is used. Severe air entrainment and foaming results in reduced hydrodynamic lubrication particularly in reciprocating engines with consequent bearing damage. Foaming in hydraulic mechanisms including the automatic transmission reduces the fluid's ability to transmit pressure because of the compressibility of the foam or air entrainment. If foaming is serious enough, it can fill the sump of the transmission and force the foaming liquid out of the filling tube with subsequent loss of transmission control, potential loss of function, and damage to the mechanism.

Much effort has been expended in applying anti-foaming agents in oil formulations to control oil foaming. To measure effectiveness of these agents, ASTM Test Methods D892 and the relatively recently developed D6082 have been established to permit measurement of an oil's tendency to foam. The methods are useful for determining the foaming tendency of a fresh oil but do not anticipate the foaming behavior of oils that are later exposed to various types of gasketing materials during operation. This exposure can extract pro-foaming agents from the gasket since, in addition to its desired duties, the oil may act as a solvent and such pro-foamants may overwhelm the action of the anti-foam additives.

Using an adaptation of a air-bath foam testing instrument, a new method of evaluating foaming tendencies has been developed to study the interrelationship between elastomeric gaskets and a chosen oil at operating temperatures. A series of experiments based on the investigative methods of Taguchi [1] were designed and conducted to rapidly explore the key variables affecting oil foaming after exposure to elastomeric gasketing materials. Several factors involved in the relationship were found very important. Others were found relatively unimportant and some were found important only under certain circumstances. Of the important factors, temperature of exposure was, as expected, among the more important. Other factors, such as oil base stock type and viscosity were also found significant. Generally, the findings were thought to offer interesting and relevant information which may aid in the future formulation of lubricating oils and fluids with reduced oil foaming tendencies. Similarly, such information and further studies may benefit the design of extraction-resistant elastomeric gaskets.

Several oil/gasket effects on foaming were suggested using the best technique indicated by the Taguchi studies. In this first paper, data will be presented showing the performance of one elastomeric rubber chemistry in different types of oils.

BACKGROUND

Ross [2-4] published a series of papers describing aeration studies and effects on lubricant foam properties. Dixon and Korcek [5] looked specifically at the role of foaming and air entrainment in automatic transmission fluids. Although, their work concentrated on entrained air, both entrained air and foam can lead to several undesirable effects. Oil with excessive air entrainment and foam will not have the same compressive properties. Performance can be seriously compromised wherever the oil is used as a hydraulic medium. The result is poor lubrication and marked potential for excessive wear and reduced service life of the mechanism.

To reduce foaming tendencies of lubricating oils, anti-foam additives are used of which silicone and other organic polymer based anti-foamants are a well known and accepted practice [6]. silicone polymers, particularly, are used extensively in motor oils and hydraulic fluids and have been shown effective in reducing oil foaming [2, 6].

As previously mentioned, ASTM Test Method D892 was developed specifically to measure lubricant oil foaming properties and, together with D6082, have been found informative. However, the initial foam-suppressing properties of the additive in an oil can later be degraded by sources of contamination that can alter the lubricant foaming properties.

In particular, when the lubricating oil comes in contact with various types of rubber gasketing materials, it has been found that such contact can extract unreacted polymer from incompletely cured gasket rubbers. These uncrosslinked or 'loose' polymers, if of the proper molecular weight, can overwhelm the effects of an anti-foam additive present in the lubricant.

EQUIPMENT AND MATERIALS

GENERAL APPROACH

In choosing a suitable experimental approach, the authors recognized that the experimental environment and the protocol of test should, if possible, be simple, versatile, and emulate to some degree the operating environment of the oil and gasket/sealant materials.

A commercial D892/D6082 foam air-bath was chosen as the test platform. 'Button sandwiches' of the sealant/gasket were exposed to the lubricant in the test cylinders and the oil or fluid tested for foaming response at any point during the test.

SEALANT MATERIAL AND APPLICATION

The elastomeric gasketing material used throughout this study was a one-component, moisture-curing, silicone RTV Sealant. These mastic types of gasketing materials act as an adhesive seal, essentially gluing the two mating parts together. During the application of the RTV, the parts are mated together and tend to squeeze out RTV material to the edges of the flange area. This bulge of sealant (sketched in Figure 1) helps provide a seal but also exposes a larger area of the RTV material to the effects of hot lubricating oil.

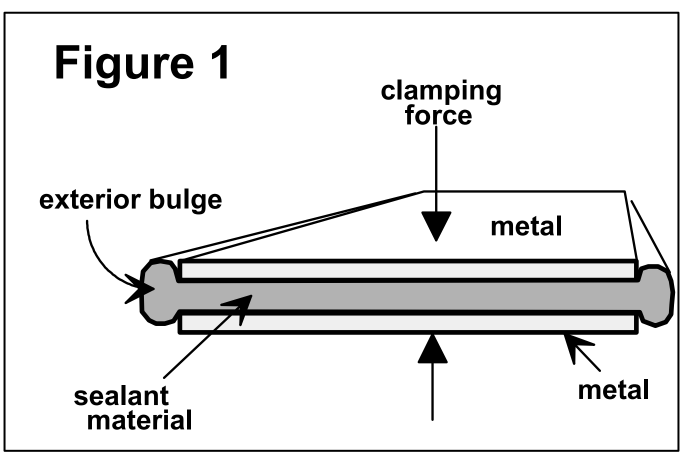

Figure 1 - Representation of RTV sealant between two mating metal surfaces.

The RTV Sealant material chosen was known to be responsive to extraction of pro-foamants and would thus be appropriate for the development and use of a method.

To imitate the exposure of the sealant to the lubricant, previously mentioned 'button sandwiches' were made. Die-cut, cold-rolled steel disks were made very flat with a center hole accomodating the hollow air tube supplying the foam head. A precise thickness and diameter of the gasketing/sealant material to be tested is sandwiched between two of these thin steel plates. When using sealants, a jig and spacers are used to control the thickness of the elastomer section. For pre-formed gasket slabs, the desired sandwich insert is simply cut out with a die punch and positioned between the two steel end plates. Figure 2 shows the resulting sandwich using an elastomer.

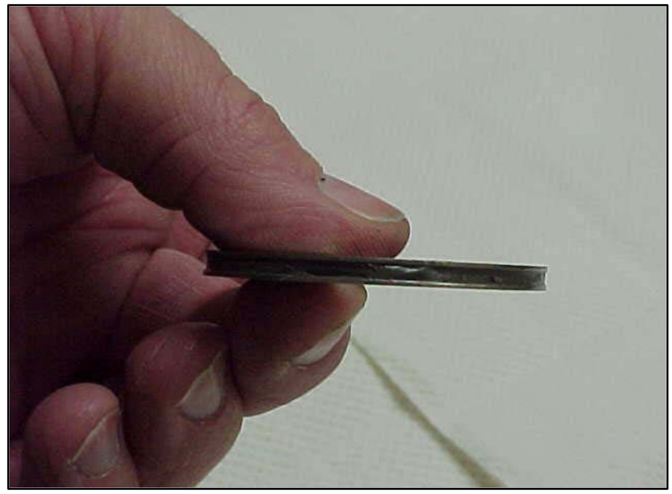

Figure 2 - Picture of a 'button sandwich' of elastomer gasketing material between two precisely spaced steel disks.

Depending on the test protocol, one or more of these sandwiches are stacked as shown in Figure 3 on the hollow steel air shaft leading to the foam-head. When assembled the foam head is placed at the bottom of a 1000 mL foam bath cylinder and the foam head and gasketing/sealant sandwiches are immersed in the approximately 200 mL volume of the test fluid in the cylinder.

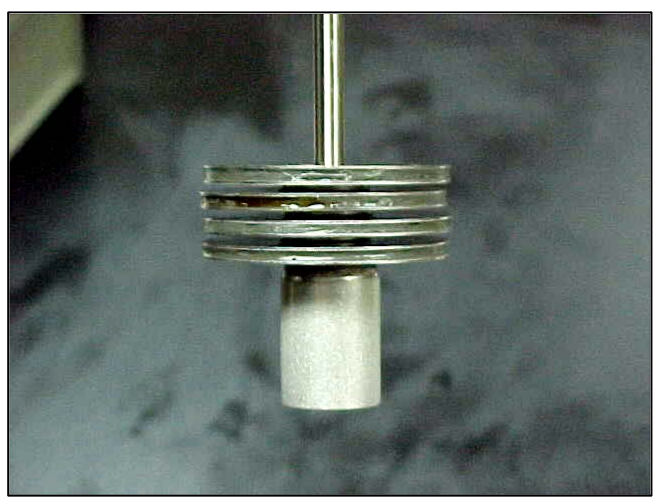

Figure 3 - Stack of four buttons of sealant placed on air-supply tube on top of foam-head.

AIR-HEATED FOAM BATH

For several reasons involving ease of operation and safety, an air-heated, foam-testing bath was chosen in preference to the older liquid bath technology. The former bath avoided the limited visibility problem developed with hot, darkening oil baths and the difficulty of transferring hot and externally slick tubes of oil from bath to bath when changing foaming temperature. The bath around which the test was developed is shown in Figure 4. (A foam test is in progress in the left hand cylinder as can be seen in the front viewing window of the air-bath.) The bath had a six-station carousel as shown in Figure 5 with two air lines attached.

Figure 4 - Air-heated foam test bath used. Two cylinders at a time are rotated by carousel (Figure 5) in front of window for view of foaming behavior.

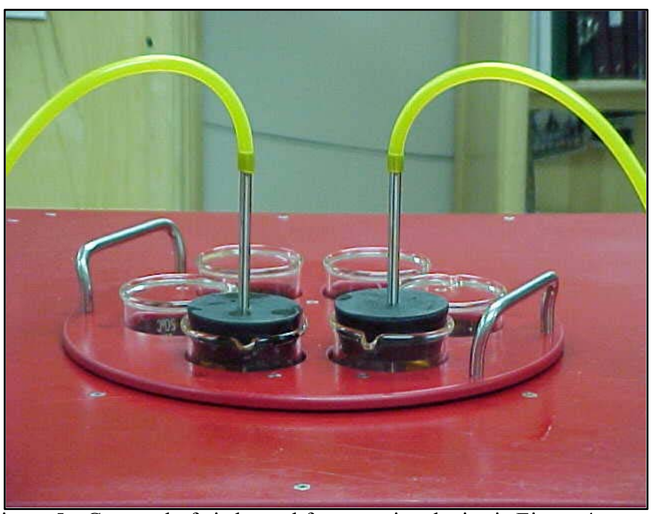

Figure 5 - Carousel of air-heated foam testing device in Figure 4 showing two cyclinders under foaming test.

One of the benefits of using an air foam bath was that, after or during tests with a given set of oils and gaskets, it was simple to change to any other temperature of interest for additional foaming tests without moving the test cylinders. Moreover, the rate of pro-foamant extraction could be determined by simply conducting a foaming test while the experiment was in progress.

From the viewpoint of versatility, the experimental approach was found to permit extraction and foaming tests on various gasketing materials over a range of temperatures up to 200°C, with variable curing and exposure times. The oils in the cylinders could be periodically agitated if desired. Variable exposure areas of elastomer could be used with various oils and fluids and various foaming protocols. In addition, the oil could be sampled during test for analysis of extractable content.

TAGUCHI METHOD

The Taguchi method [1] was designed to obtain the maximum amount of information from the least number of experiments. Different suspected influences (Factors) on a given property (such as foaming tendency) are selected at two considerably different but reasonable levels (e.g., a lower and a higher temperature of test). This selection of a sufficiently different levels helps in establishing whether or not, and to what degree, the chosen Factors are influential, relative to one another. In the course of these Taguchi experiments, several possible influences on foaming tendency were evaluated using the technique. Some expected influences were surprisingly low and, interestingly, some varied according to foaming test temperature.

RESULTS AND DISCUSSION

PRELIMINARY TEST OF REPEATABILITY

Before embarking on the Taguchi studies it was important to first determine the repeatability of the proposed experimental approach.

A 24-hr, 150°C preliminary study of the proposed test method using the air-bath foam apparatus was made. The study involved determining foaming tendencies of 200 mL of the following:

1) a fresh commercial ATF,

2) the ATF exposed to four special buttons having a total 64-cm long bead with 128 mm² area, and

3) four buttons having a total 64-cm long, elastomer bead area of 958 mm².

The foaming tendency tests were run at 150°C in duplicate and each test oil in each cylinder was run three times and averaged. Results of both the individual determinations and the averages are shown in Figure 6.

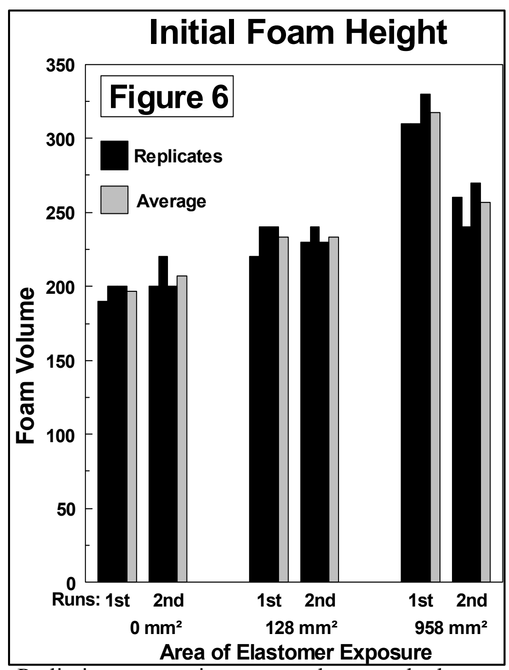

Figure 6 - Preliminary run using proposed test method to examine its repeatability.

Taking into account that this was the first test conducted using the proposed method, repeatability was found reasonably good with the partial exception of the largest area of elastomer exposure. Beyond repeatability information, this preliminary test showed that the presence and the amount of elastomer increased foaming over that of the unexposed ATF. The latter, interestingly, showed comparatively high foaming tendency even though presumably treated with an antifoam additive. To this innate foaming tendency, the exposure to 128 mm^2 of elastomer added about 12% more initial foam and the 958 mm^2 of elastomer added 38% more foam.

It was also noted that the rate of foam decay was slowed by the presence of the elastomer. On the basis of these results, work was started on a seven-variable study.

SEVEN FACTOR STUDY

To initiate the entire study, a first effort was made to choose among several apparently important variables and eliminate any that were indicated to be of minor effect on initial foam height. The aforementioned Taguchi approach [1] was used.

Table 1 shows choice and range for a seven-variable Taguchi matrix requiring eight trial tests. The variables were chosen as seeming of most relevance to the issue of generating pro-foaming extractants from gasketing materials.

Table 1 - Factors, Description and Levels

FACTORS	DESCRIPTION	LEVEL 1	LEVEL 2
A	Cure Time	5 min.	72 hrs.
B	Surface Area Exposed	0.2mm	1.5mm
C	Naphthenicity of Oil	0%	50%
D	Additive Pkg. Content	25%	100%
E	Oil Agitation	End of Test	Every 12 hrs.
F	Oil Temp. Temperature	Room Temp.	150° C
G	Exposure Time to Oil	24 hrs.	7 Days

Table 1 - Choice of variables and range for first Taguchi study.

<u>Special Factors</u>

Base Oils Factor

Two simple non-additized base oils of different levels of naphthenicity were chosen to see how a presumably more solubilizing oil (increased naphthenic content) would influence pro-foamant extraction.

Additive Package Factor

To these base oils were added an automotive engine oil additive package at 100% normal level and at 25% of that level to see what influence this difference in levels might have. Any difference, of course, would pertain only tothis one set of additives.

<u>Results, General</u>

The individual influences of the aforementioned seven Factors on foam height were measured using a slight modification of ASTM D6082 at 150°C. In this case, rather than 180 mL required by D6082, 200 mL of oil were exposed to the sandwich discs during the period of test. In addition, the modified foam test was conducted with the sandwich discs in place. Flow rate of the air was kept the same as in D6082.

Effects on Initial Foam Height

Results are shown in Figure 7. As can be seen, very different foam levels were observed, indicating good differentiation among the variables chosen. Also shown in Figure 7 is fairly good repeatability among the three readings from each trial.

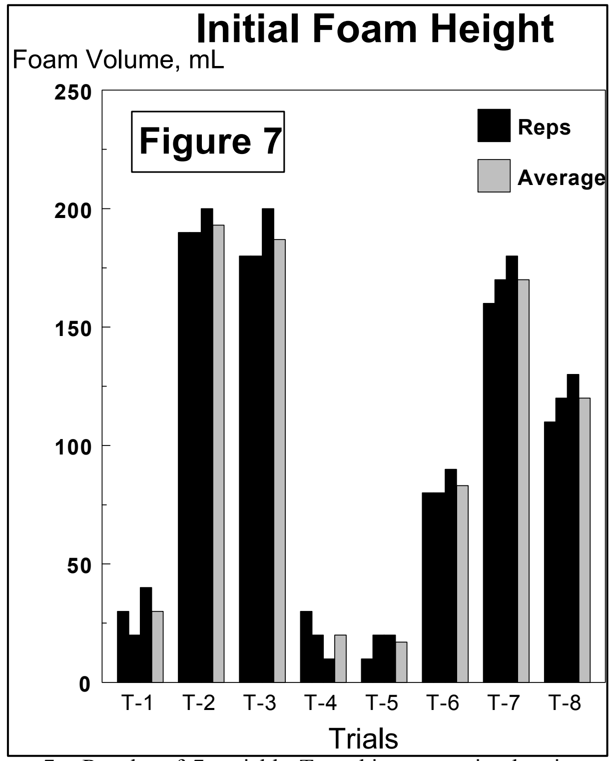

Figure 7 - Results of 7-variable Taguchi test matrix showing good differentiation and repeatability.

Determination of Strength (Level) of Factors

Using the Taguchi technique, the foam height data shown in Figure 7 was then used to calculate the significance and direction of influence (level) of the various Factors chosen. Results of this analysis is shown graphically in Figure 8.

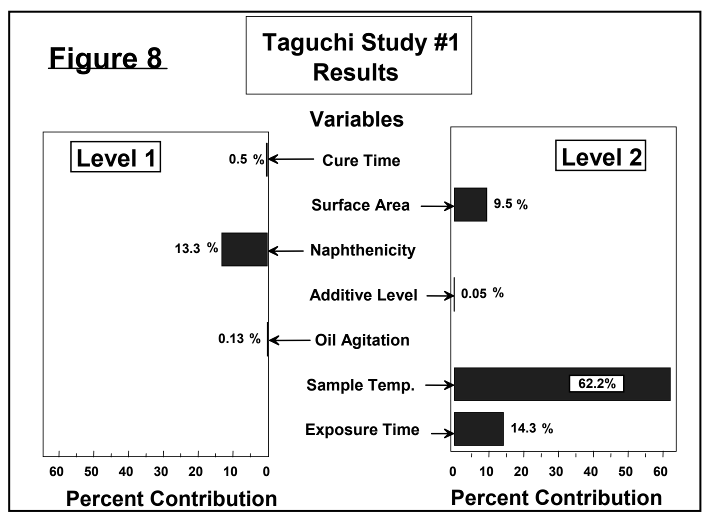

Figure 8 - Analysis of 7-variable Taguchi test matrix showing considerable differences among Factors.

General Significance of Levels and Percent Contribution - In Figure 8 and in all similar following graphs, Level 1 is associated with the lower level of a Factor or with a particular composition being contrasted to another. Thus, Level 2 represents the higher level of a Factor or the composition of a second material. Contributions from both Levels 1 and 2 total 100%. Thus, the higher the contribution the more important the Factor whether in Level 1 or Level 2. In other words, one may have either a strong negative or a strong positive effect of a given Factor. In the author's view, a Factor's contribution was considered meaningful at a level of 5% or higher.

Analysis of Data from Seven-Factor Taguchi Study

Using initial foam height, results are shown in Figure 8. Of the seven Factors studied, one shows a large effect, three show moderate effects, and three show little or no effects. Both negative and positive effects are shown.

Those Factors of the seven showing negligible effect on initial foam height when measured at 150°C are:

- Cure time
- Specific automotive package additive
- Agitation of the oil during test.

Those Factors of the seven having significant effect are:

- Temperature of the oil
- Naphthenic content (negative effect)
- Exposure time
- Surface area exposed.

Temperature of the Oil - Of these, the largest single positive Factor is elastomer oil exposure temperature (i.e.,150°C » room temperature). While, in general, solubilization would be expected to increase with increasing temperature, this is not the only relationship believed involved. Another effect may be that higher oil temperatures swells the silicone rubber matrix allowing for easier extraction of any pro-foamant polymer from the gasketing/sealant material.

Mineral Oil Solvency - Interestingly, the more paraffinic the oil (the lower the naphthenicity) the higher the foaming tendency. This suggests that the short linear chains of paraffins have greater ease in penetrating the temperature-expanded mastic than the bulkier naphthenes.

Exposure Time and Area Exposed - Both of these latter Factors are interrelated since the greater the area exposed, the more rapidly extraction can take place.

Summary of First Results

As mentioned, of the seven Factors, four were shown to be either unimportant (cure time of the RTV, additive level, oil agitation) or indicative of the solvency effect (shape and size of oil molecules). In contrast, bath temperature, surface area, and exposure time accounted for over 85% (with solvency effect, 99.7%) of the extraction effect.

Application to Further Studies

Putting this information to use, the authors decided that the focus of next Taguchi tests would be to use three-Factor tests with temperature held constant at 150°C and exposure time set at 120 hours. Curing time and agitation of the sample were not apparently highly influential. By holding important Factors such as temperature as constant, the impact of other variables such as surface area, viscosity, and base oil type could be explored. Generally, holding any chosen significant Factor as a constant permits examination of other Factors.

COMMERCIAL GEAR OILS

With the results from the seven-Factor Taguchi test in hand and tending to confirm the ability of the new test method to discriminate among various operating conditions and Factors, the authors then moved into an evaluation of some readily available commercial oils using the same silicone RTV gasketing material.

Hypoid gear oils have been shown to display very high levels of foam after contact with gasket/sealant materials and two were selected for study of base stock effects.

Study of Mineral and Synthetic Oil Effects

Test Setup

As shown in Table 2, two gear oils with quite different base oil were chosen as one of the three Factors. In addition, the

Table 2 - Gear Oils Used in Study

SAE Grade	Base Oil	Viscosity @ 100°C, cSt.
85W-140	Mineral	25.82
75W-140	Synthetic	25.34

Table 2 - Viscosity grade, base oil characteristics, and viscosities at 100°C of two hypoid gear oils.

surface area exposure of the sealant was varied, and finally, the length of exposure was varied as shown in Table 3. Temperature and sample volume were held constant at 150°C and 200 mL, respectively.

Table 3 - Gear Oil Taguchi Study

FACTORS	DESCRIPTION	LEVEL 1	LEVEL 2
A	Base Oil	Mineral	Synthetic
B	Surface Area Exposed	0.2mm	1.5mm
C	Exposure Time to Oil	24 hrs.	120 hrs.

Table 3 - Factors and description at two levels of a synthetic and a mineral oil hypoid gear oil .

The four Taguchi tests required are shown in Table 4. Additive types and levels were not known.

Table 4 - Gear Oil Taguchi Study - Trials

Trials	Base Oil	Area	Exposure
#1	Synthetic	0.2	24 hrs
#2	Synthetic	1.5	120 hrs
#3	Mineral	0.2	120 hrs
#4	Mineral	1.5	24 hrs

Table 4 -Taguchi trial setup for studies of importance of base oil type, area of gasket exposed, and exposure length.

Dual Foam-Test Temperatures

At least one of the in-house bench tests developed by OEMs is run at room temperature and it was of interest to determine what effect temperature of foaming had on the apparent influence of Factors. Perhaps Factors important at higher temperatures might be found of negligible effect at lower temperatures.

To determine the foaming behavior of these gear oils at other temperatures, it was decided to obtain initial foam heights at both 150°C and at room temperature (RT) following the completion of the test. This would also give information regarding differences, if any, in effects on foam height.

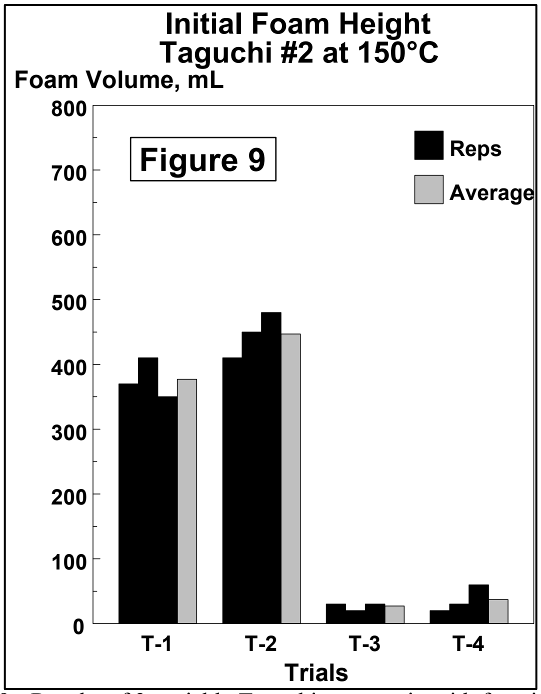

Figure 9 - Results of 3-variable Taguchi test matrix with foaming test run at 150°C.

Results from 150°C Foaming Temperature - Figure 9 shows the foaming results at the higher temperature. Appraising this figure, considerable differences are apparent between theTrials T-1/T-2 and T-3/T-4. The primary difference in the makeup of the trials (see Table 4) is that the synthetic gear oil was used in Trials T-1 and T-2 while the mineral gear oil was used in Trials T-3 and T-4. This suggests two reasonably likely causes:

1. The synthetic oil itself may be much more prone to foam at 150°C, and/or

2. The synthetic oil is much more efficient in extracting pro-foamants.

Taguchi Analysis of 150°C Results - The graphical presentation of the Taguchi Analysis of the 150°C foaming tests is shown in Figure 10. As anticipated from Figure 9, the synthetic oil Factor dominates either of the other two Factors, surface area and exposure time. Results such as these suggest a further Taguchi test in which the oil is held constant as well as the test temperature to reveal the possible effects of Factors such as surface area and exposure time.

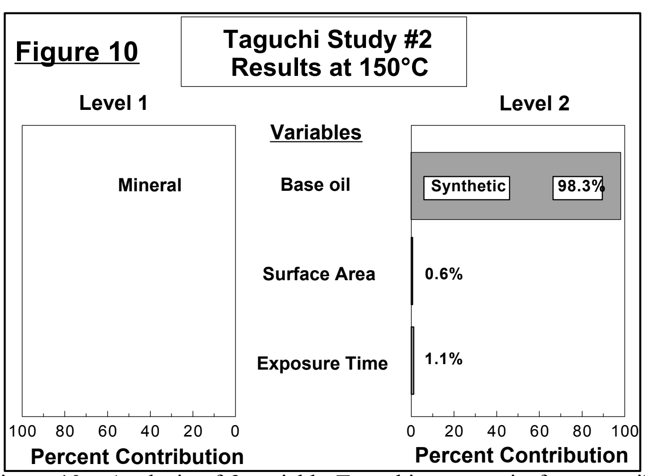

Figure 10 - Analysis of 3-variable Taguchi test matrix for gear oils foamed at 150° C.

Results from Room Temperature Foaming Test - Following the 150°C foaming tests, the four cylinders of test oils were left in place in the foam air bath and carousel shown in Figures 4 and 5. The bath was then rapidly cooled to room temperature using the bath's internal water cooling coils and the foaming tests repeated.

Figure 11 shows the foaming results from this RT set of tests. There are clearly evident differences from the results previously shown in Figure 9. The most evident difference is

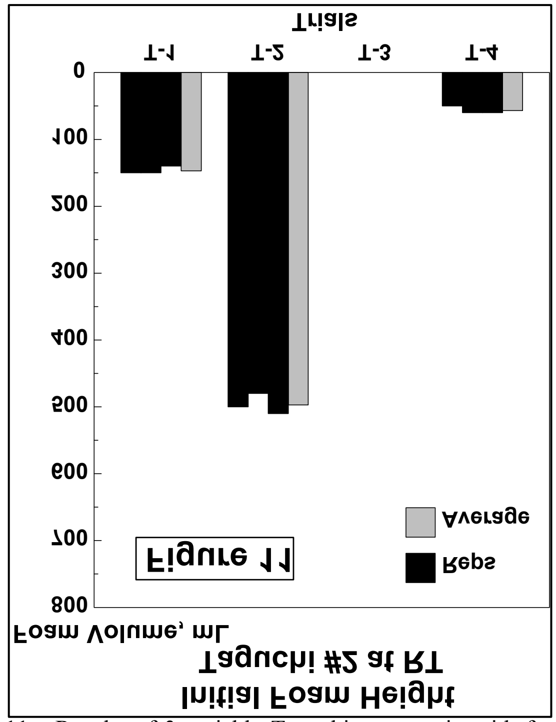

Figure 11 - Results of 3-variable Taguchi test matrix with foaming test run at RT.

the reduction in initial foam height generated by Trial T-1 and the disappearance of even a small reponse in Trial T-3. On the other hand, Trial T-2 in the RT study seems to show a somewhat increased foam height over that in the 150°C study.

Taguchi Analysis of Room Temperature Results - Figure 12 shows that the relationship exhibited in Figure 10 has shifted considerably when the foaming temperature was reduced to room temperature. The contribution of the base oil is still strongly dependent on the synthetic oil Factor at almost 58% of the total. However, the Factors of surface area exposed and

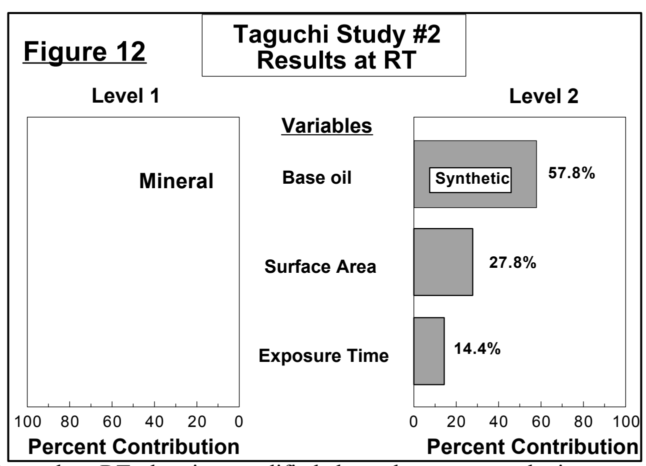

Figure 12 - Analysis of 3-variable Taguchi test matrix for gear oils foamed at RT showing modified dependence on synthetic gear oil Factor and emergence of surface area and exposure time Factors.

and exposure time are now expressed at significant levels of 27.8% and 14.4%, respectively.

This second (RT) condition of foaming shows that the influence of a given Factor is not only affected by the temperature of foaming but in turn reveals or obscures the influence of other Factors. The practical meaning is that it may be desirable and informative (after pro-foamant extraction at a higher temperature) to conduct foaming tests at more than one temperature.

Other Parameters; Foam Collapse Time

Parameters other than initial foam height can be used to appraise the influence of Factors. Foam collapse time is one, silicon content is another.

Just as in Figures 9 and 10 the foam collapse times for the gear oils are also highly affected by the type of base oil used, as is shown on Figures 13 and 14. Figure 14, in particular, shows that more that 99% of the extension in collapse time can be attributed to the effects of the synthetic gear oil.

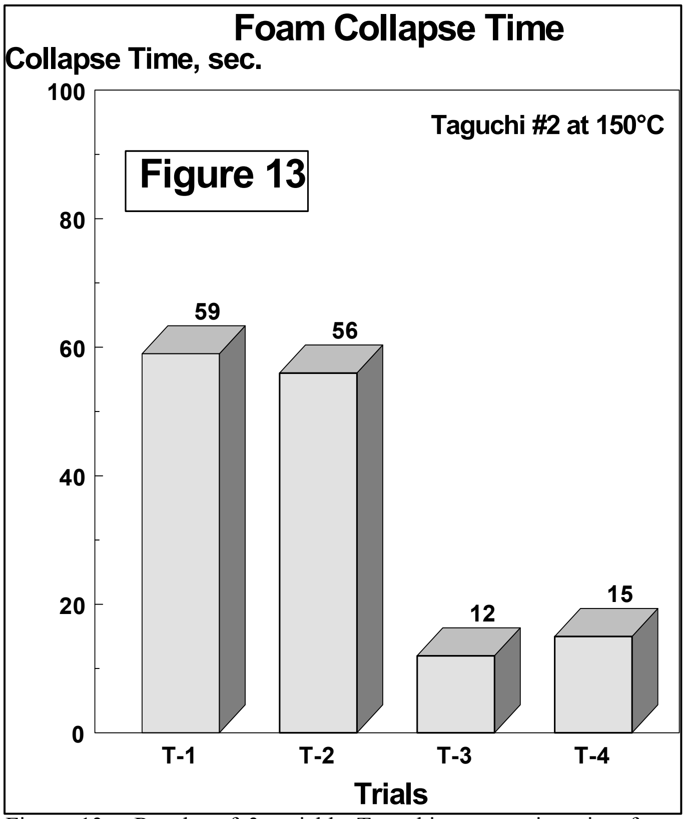

Figure 13 - Results of 3-variable Taguchi test matrix using foam collapse time at 150°C as the test parameter.

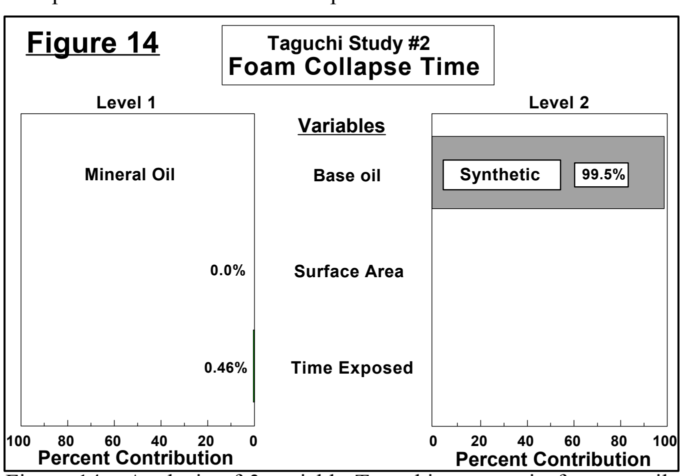

Figure 14 - Analysis of 3-variable Taguchi test matrix for gear oils using foam collapse time at 150°C as the test parameter.

Effect of Viscosity

Considering Factors involved in pro-foamant extraction, one of the questions raised by the foregoing gear oil study involving synthetic and mineral oil base stocks involved separating the Factors of composition from the Factor of viscosity on gear oil foaming. Higher viscosities are associated with larger molecules of either or both the base stock and certain additives and, thus, such molecules might be more inhibited in extracting pro-foamant material on the basis of a molecular size effect suggested by the earlier Seven Factor study).

To initially investigate the importance of the viscosity Factor in contrast to the base oil source Factor, two commercial mineral gear oils with very different viscosities were selected. The properties of these two mineral oils are shown on Table 5. Again, the RTV gasketing material used in the previous studies was used.

Table 5 - Gear Oils Used in Viscosity Study

SAE Grade	Base Oil	Viscosity @ 100°C, cSt.
80W-90	Mineral	14.15
85W-140	Mineral	25.82

Table 5 - Base oil characteristics and viscosities at 100°C of two hypoid gear oils having mineral oil basestocks.

Table 6 - Taguchi Mineral Gear Oil Viscosity Study - Trials and Factors

Trials	Viscosity	Area	Exposure
#1	14.15 cSt	0.2	24 hrs
#2	14.15 cSt	1.5	120 hrs
#3	25.82 cSt	0.2	120 hrs
#4	25.82 cSt	1.5	24 hrs

Table 6 -Taguchi trial setup for studies of viscosity, area of gasket exposed, and exposure time Factors.

Effect of Viscosity on 150°C and RT Foaming Temperatures

The initial foam heights and Taguchi analyses for both 150°C and room temperature are shown on Figures 15 through 18, respectively.

First of all, it is evident that there is much difference among foam heights at these two temperatures and consequently much error possible in interpretation of results if only one of the two test temperatures of foaming tendency were used.

Of equal significance, trials conducted with lower viscosity oil and higher temperature are much more prone to foam (see Figure 15) than at lower temperature where the viscosities are considerably more proportionately similar. At room temperature, the two Trials with greatest surface area show slightly more tendency to impart foaming tendencies (see Figure 18).

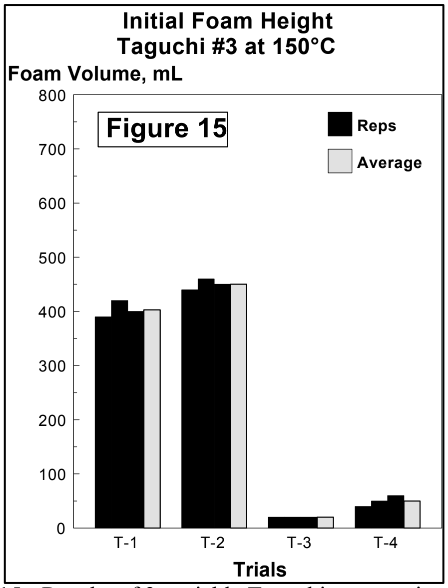

Figure 15 - Results of 3-variable Taguchi test matrix of Table 6 with foaming test run at 150°C.

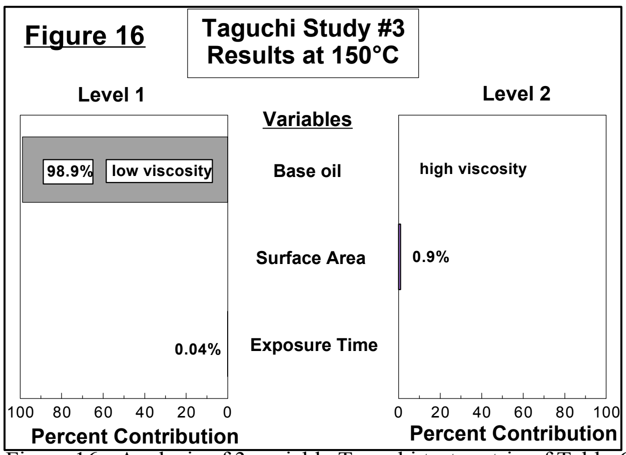

Figure 16 - Analysis of 3-variable Taguchi test matrix of Table 6 and Figure 15 for mineral gear oils foamed at 150° C showing very high dependence on lower viscosity gear oil Factor.

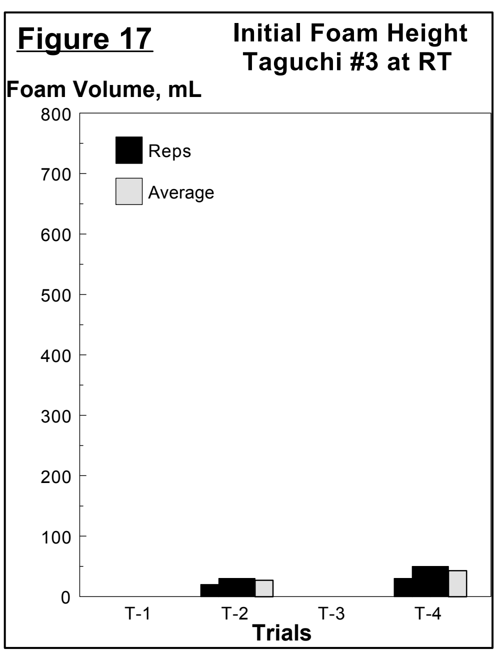

Figure 17- Results of 3-variable Taguchi test matrix of Table 6 with foaming test run at RT.

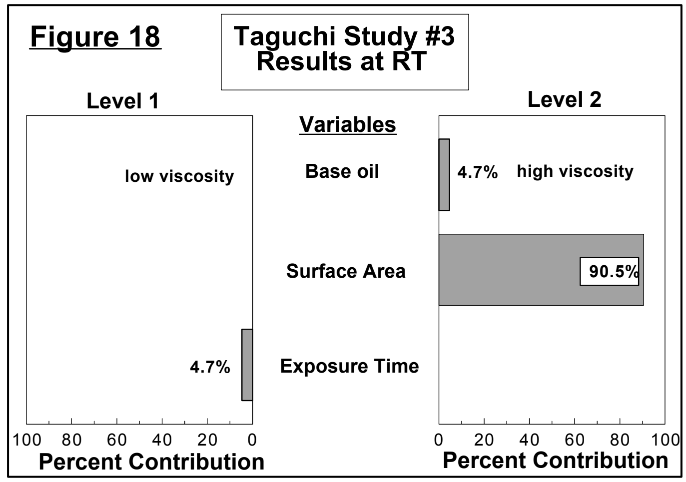

Figure 18 - Analysis of 3-variable Taguchi test matrix of Table 6 and Figure 17 for mineral gear oils foamed at RT.

COMMERCIAL ATFs

Two commercially available automatic transmission fluids were next evaluated, one formulated with mineral oil and the other with a synthetic-based oil. The kinematic viscosities for the two ATF's at 100°C were almost identical as shown in Table 7.

Table 7 - ATFs Used in Study		
Brand	Base Oil	Viscosity @ 100°C, cSt.
A	Mineral	7.67
B	Synthetic	7.64

Table 7 - Base oil characteristics and viscosities at 100°C of a synthetic-based and a mineral oil-based ATF.

Exposure temperature was held constant at 150C and the analysis of initial foam height was conducted at the same temperature. Table 8 shows the variables used in the ATF study. Once more, the RTV gasketing material was used.

Table 8 - Taguchi ATF Viscosity Effect Study - Trials			
Trials	**Base Oil**	**Area**	**Exposure**
#1	Mineral	0.2	24 hrs
#2	Mineral	1.5	120 hrs
#3	Synthetic	0.2	120 hrs
#4	Synthetic	1.5	24 hrs

Table 8 -Taguchi trial setup for studies of viscosity, area of gasket exposed, and exposure time Factors.

Initial foam heights are shown in Figures 16 and 17. Here the data shows less impact from the type of base oil than was shown in the Gear Oil study, although the synthetic ATF does promote higher foam levels. The most significant variable is the exposure time of the RTV

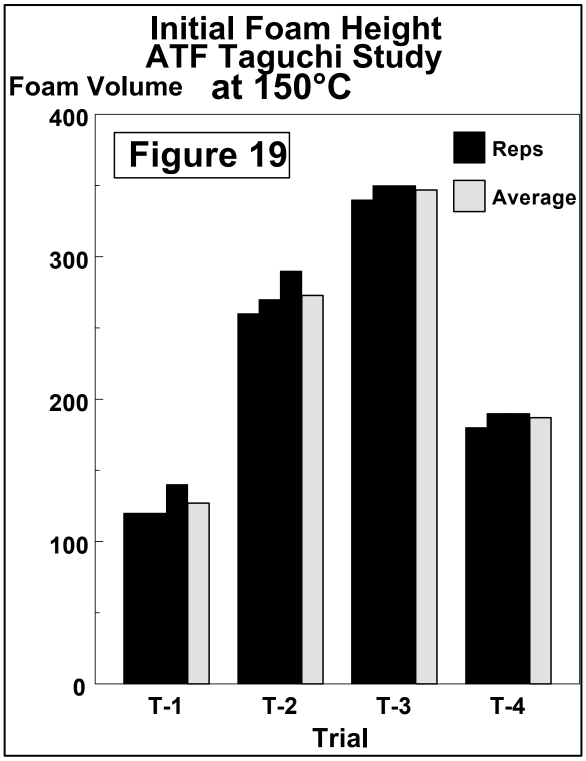

Figure 19 - Results of 3-variable Taguchi test matrix of Table7 with foaming test run at 150°C.

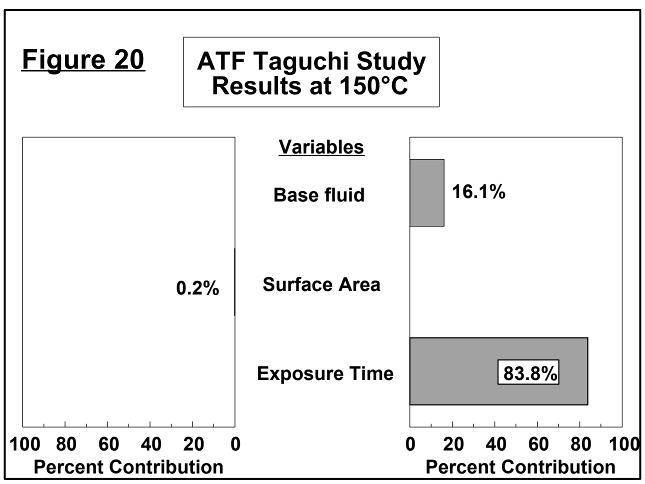

Figure 20 - Taguchi matrix analysis of the test results shown in Figure 19.

GENERAL DISCUSSION

The foregoing data have been presented to show the application of a new and versatile test method for determining the extractability of pro-foamants from gasketing material. Choice of the Taguchi matrix method of determining the relative influence of various Factors or variables on foaming response was based on the ability to rapidly separate these variables and their importance.

STRENGTH OF THE TAGUCHI METHOD

The strength of the Taguchi method is in rapidly sorting through a number of test variables to determine their respective influence on the parameter being studied. In the present work, this strength was best shown in the seven-Factor study in which these Factors were evaluated and those most influential chosen for further studies.

CARE INTERPRETING TAGUCHI METHOD RESULTS

When using the Taguchi matrix method it must be understood that other Factors outside of those chosen for examination can and do influence results depending on the parameter being measured. Initial foam height may be a function of the oxidation of a given oil as well as being affected by the extraction of pro-foamants. Such Factors and their effects must be evaluated. For example, if the foaming tendency of the oil or fluid itself is a hidden Factor (e.g., in the case of comparing two oils), the test will be affected. To remove or, at least, measure such effects on the results of a Taguchi study, it is necessary to run the two oils or fluids through the temperature and foaming test without exposure to the gasketing material and thereby generating a baseline for comparison to values observed in the Taguchi test.

In the tests conducted and presented in this paper, there was no attempt to determine the inherent foaming tendency of the various oils and fluids. Until this data is gathered, the value of the present study is simply in demonstrating a technique of testing gasketing materials and their interaction with oils and hydraulic fluids. Further studies will examine the inherent contribution of these oils to foaming conditions.

TEST METHOD

In developing a test protocol, it is important to know and select those controllable variables (Taguchi Factors) having greatest influence in pro-foamant extraction. These variables can be set as test parameters at meaningful levels for comparative tests of the oil/gasket relationship.

In the Appendix to this paper the authors give a test method they have generated from more extensive studies of Factors and conditions than presented in this paper.

FUTURE WORK

There are several areas already mentioned that are planned for further work. One of these is to determine the influence of innate foaming tendencies of the oils and fluids used in the present study. Another is to evaluate the extraction of silicon and other gasketing profoamants and to analyze these data using the same Taguchi techniques.

Still another area is to measure the rate of extraction of silicon by direct measurement of small samples taken during a test and/or by foaming the test oil or fluid during the extraction.

CONCLUSIONS

METHOD DEVELOPMENT

Presently known methods for testing the effects of lubricating oils and hydraulic fluids on gasketing material have not been found to adequately address the variables of the oil/gasket contact in service.

In this paper the authors have presented the development and use of a new, versatile, and repeatable method for determining the susceptibility of gasketing materials to the oils and fluids bathing them. The test method permits a controlled area of the gasket or elastomer to be exposed to an oil in the same device in which a foaming test may later be run during or after exposure.

Further, the method permits both exposure and foaming tests to be carried out independently at different temperatures of choice up to 150°C and more.

APPLICATION OF METHOD

Using Taguchi matrix techniques, application of this method has revealed the level of importance of several variables in causing foaming conditions. Influences such as temperature of exposure, gasket area, type of base oil, viscosity, curing time, etc. have been evaluated and compared in preliminary studies.

Using initial foam height (with no correction for innate foaming tendency of the oils) it was found that the temperatures of exposure and subsequent foaming were highly influential. Interestingly, cure time for the silicone RTV was not. Viscosity of the oil seemed to have marked effect on the pro-foamant extraction of gear oils.

In general, it is clear that the RTV silicone exposure conditions are critical to accurately observing and measuring foam levels. These important exposure conditions were identified in the studies and clarified in the follow-up experimentation.

To reduce or eliminate the foaming tendency of oils, the authors recommend that automotive design engineers, elastomeric gasket suppliers, and lubricant manufacturers work closely. The data obtained with this new test method can be used effectively to appraise and screen the oil/elastomer interrelationship of gear oils, ATFs, and engine oils under many operating conditions.

Appendix 1 proposes a new test method built around the findings in this paper.

ACKNOWLEDGMENTS

The authors wish to thank all those who assisted them in the work reported. This includes the efforts of Larry Schember, Jennifer Richardson, and the Peer Reviewers of the paper.

REFERENCES

[1] Roy, R., **A Primer on the Taguchi Method**, Van Nostrand-Rheinhold, 1990.

[2] Ross, S. and Suzin, Y,, "Lubricant Foaming and Aeration Study", Technical Report AFWAL-TR-82-2090, US Air Force. Wright-Patterson Air Force Base, OH (1982)

[3] Ross S. "Lubricant Foaming and Aeration Study", Part I, Technical Report AFWAL-TR-84-2001. US Air Force. Wright-Patterson Air Force Base, OH (1984)

[4] Ross. S. "Lubricant Foaming and Aeration Study", Part II, Technical Report AFWAL-TR-84-2001. US Air Force. Wright-Patterson Air Force Base, OH (1985)

[5] Dixon, L. T. And Korcek. S., "Foaming and Air Entrainment in Automatic Transmission Fluids", SAE Publication No. 760678 (1976)

[6] Chemistry and Technology of Silicones, Noll, W., Academic Press, N.Y., pp. 626-627 (1969)

APPENDIX

PROPOSED TEST METHOD FOR DETERMINING OIL/GASKET FOAMING TENDENCY

GENERAL

Oil and hydraulic fluid can extract pro-foamants from elastomeric gasketing materials and increase the foaming tendency of lubricating oils. To control this problem on an industry-wide basis, standardized equipment and procedures must be established. The following proposed procedure uses equipment readily available to test the pro-foamant extraction interrelationship between oils and gasketing material.

For Use With Air-Heated Oil Foam Bath (other baths may be modified to function in a similar manner)

Pre-test Procedures:

Record type of rubber to be tested and source (lot number)

Be sure all equipment has been solvent cleaned and dried

Sample Preparation:

Slab

1. For high consistency silicone rubber, liquid silicone rubber, or other organic molded rubber, be sure that material has been fully compounded and post cured. For moisture cure 1- or 2-part RTV's, allow seven days full cure at room temperature and 50% relative humidity.
2. Slabs shall be 1.5 mm in depth. After the rubber is fully cured, cut discs from the slabs in 52 mm sections using a punch.
3. The cured discs are then sandwiched between two 0.030" very flat steel discs[1] of the same diameter so that only the edge is exposed. Adhesive is used to bond the steel discs to the surface of the rubber and the assemblies place in a mild press or jig to allow the adhesive to bond.
4. Four discs are normally used for each test so that total of 960 mm^3 of cured rubber is edge exposed. Alternatively, other cured rubber thickness can be used to obtain a total of 960 mm^3 of edge exposed rubber.
5. Cured discs are to be mounted onto the aeration tube that is inserted into the 1 L graduate.

Mastic

1. Mastic is applied with an applicator to one side of each steel disc in a series of radial spokes to permit closure to eliminate air pockets.
2. A special spacer[1] of 1.5 mm thickness is imbedded into the mastic so that its central hole aligns with the holes in the steel discs. A special jig[1] is used to press the steel discs together to form steel-mastic-steel 'sandwiches.

Test Procedure:

1. Heat in an oven 200 mL of oil to be tested and pour into one of the 1 L graduated cylinder
2. With the cured rubber discs already threaded on the aeration tube, into the test oil, insert aeration tube in cylinder.
3. Turn on temperature bath and set at 150°C.
4. Run exposure at 150°C for 100 hours.

Foam Height Measurement:

1. Exactly at 100 hours of exposure, run the "hot" foam height measurement by aerating the test chamber with 200 ml/min of air flow. Record foam height at 5 minutes. Record the time for foam to collapse.
2. Cool test oil to 25 C. Measure "cold" foam height by aerating the test chamber with 200 ml/min of air flow. Record foam height at 5 minutes. Record the time for foam to collapse.

[1] Contact authors for sources, if interested.