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Experimental Investigation and prediction of viscosity and contamination percentage of fuel dilution in oil as a function of temperature for turbo machinery

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ABSTRACT: Engine oil plays a vital role in turbo machinery for its function, performance and safety. Part failure of lubrication/fuel system in gas turbine engine can lead to contamination of oil by fuel. The fuel dilution in the oil has an effect on the physical properties. This paper experimentally investigates viscosity (μ) change with contamination levels at different temperatures. Experiments conducted for contamination range of 0 -100% from 25deg C to 100 deg C showed an exponential decrease with contamination and temperature by a factor of 0.046 and 0.01312 to 0.03206 respectively. Theoretical prediction of viscosity showed high error percentage and standard deviation. Linear regression analyses were carried out between contamination, viscosity and temperature and an empirical relationship with R square of 0.99 is developed. The relationship enables identification of percentage contamination of oil and measurement of its viscosity at different temperatures. This forms an important diagnostic tool for condition monitoring of lubrication oil.

KEYWORDS: Viscosity, Temperature, Contamination, Regression analysis

I. INTRODUCTION

Lubrication oil in turbo machinery plays the role of reducing friction, minimizing wear, effective cooling, reduce corrosion and carry away deposits [1]. Contamination in oil due to the operation condition will change the properties of oil leading to improper lubricating and cooling of bearings [2].Measurement and analysis of oil properties like viscosity (μ), flash point, fire point, density, total base number, etc., provides information on oil contamination [3]. Dilution of fuel in the oil increases the volatility, \educes the thickness of the oil film and viscosity leading to degradation in the performance of the lubrication system and increase in oil consumption. [4]. Viscosity of oil decreases with increase of temperature and the decreasing rate follows an exponential relationship [5]. From the literature it is observed that there is an instant gradient decrease in viscosity for each contaminated percentage with increase in temperature [6].Theoretical models for prediction of viscosity for binary mixtures are reported in the literature [7].It is observed that not all binary mixtures follow similar trend of predicted theoretical models so, empirical relationships are developed with the experimental data through regression analysis.

Ljubas et.al [1] had conducted experiments by contaminating oil with fuel in the range from 0 to 10% by weight ratio for studying the effect on physical properties of oils. They found that as contamination increases there is a decrease in the viscosity, flashpoint and fire point of oil and also defined an acceptable contamination percentage for oil usage in engine. Tingjun Hu et.al [3] had conducted experiment on oil contamination with gasoline contamination up to 10% by weight ratio for studying the effect of viscosity, Total Acid Number and flash point. Acceptable limit of viscosity limit was established at 9% contamination for particular oil fuel contamination. Shreya N. Sahasrabudhe [5] Viscosity measurement performed on different five oil types from 23 - 200°C at intervals of every 20°C. All oil type was shown to have a significant effect on viscosity and density. Viscosity decreased exponentially with increasing temperature. Su Han Park[6] Experimental investigation and prediction of viscosity and density for different Blending from 10 – 100% by volumetric ratio with function of temperature range from 20 -150°C.The densities of blends decreased linearly with increasing fuel

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temperature but the dynamic and kinematic viscosities of blends decreased exponentially with increasing fuel temperature. Empirical correlations for densities and viscosities have been derived for variations in fuel temperatures and blending ratios. Schmirler Michal1[7] Performed experiments to determine the viscosity of mixture and compared the experimental results with several other sources of determining viscosity theoretically and determined suitable method for calculating viscosity which is closer to the experimental results. BorisZhmud [8] Different theoretical blending equations are used to predict the viscosity of the binary mixtures. Kendal Manroe equation (Eq. 01)for calculating the viscosity of the mixture as the cube root average of the mixture component viscosity and Arrhenius equation (Eq. 02) &'Grunberg Nissan equation'(Eq.03) by natural logarithmic function. Where 'μ' is the viscosity component and 'χ' is the mole fraction component.

$$\mu_{12}^{1/3} = x_1\mu_1^{1/3} + x_2\mu_2^{1/3} \quad \text{(Eq.01)}$$
$$\log \mu_{12} = x_1 \log \mu_1 + x_2 \log \mu_2 \quad \text{(Eq.02)}$$
$$\ln \mu_{12} = x_1 \ln \mu_1 + x_2 \ln \mu_2 \quad \text{(Eq.03)}$$

Where,
1 = Oil
2 = Fuel
x1,x2 = Volume fraction of liquid 1 & 2.
μ1,μ2 = Dynamic Viscosity (mPa.s)
μ12 = Mixture Viscosity

II. MATERIALS AND METHOD

a. Fluid Properties

For the study of effect of viscosity on contamination, the selected oil and fuel are Turbonyc 600 oil and Jet A1 fuel which complies with MIL PRF 2699 and Def-Stan 91-091 standard respectively.

Properties	Turbonyc 600 oil	Jet A1 Fuel
Viscosity (μ)	4.90 – 5.40 mm2/s @ 100˚C	max 8.00mm2/s @ -20°C
Flash point	269°C (Open Cup Method)	>38°C
Density(gm/cc)	0.993kg/dm3 @ 20°C	>775, <840kg/m3 @ 15°C

b. Equipment Description

The highly precise Stabinger Viscometer used for measurement of viscosity and density of the samples and the method complies with ASTMD 7042 which is capable of measuring viscosity and density in the range of 0.2 mm²/s to 30000 mm²/s and 0.6 g/cm³ to 3 g/cm³ respectively. The kinematic viscosity gets calculated from the measurement of dynamic viscosity and density of the given sample.

$$m_0 + m_f = m_s$$
$$m_f = m_s - m_o$$
$$m_f = \rho_f \times v_f$$
$$v_f = m_f/\rho_f$$
$$v = m_s/\rho_s$$

Where,
m_0 ---Mass of the oil
m_f ---Mass of the fuel
m_s ---Total Mass of the Sample
ρ_f --- Density of the Fuel
v --- Total Volume of the Sample
ρ_s--- Density at ambient condition

c. Sample Preparation

The mixture of oil and fuel were prepared by weight method and the equation for calculating the percentage volume is illustrated here.

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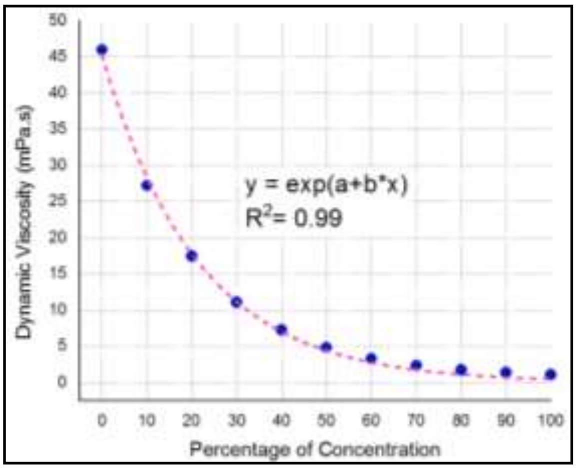
III. RESULTS

This section presents the quantitative results of viscosity measurements with respect to the contamination percentage. Experiments were carried out for viscosity from 0-100% contamination. Two sets of measurements were carried out for each percentage of contamination and the average viscosity value is plotted against contamination.

a. The change in viscosity for contamination percentage in steps of 10 % at the temperature of 25deg C is presented in Figure 2. It has been observed that a viscosity decreases with increase in contamination percentage.



b.

Figure 2. Change in viscosity w.r.t Contamination percentage in steps of 10%

b. Viscosity for contamination range of 0-100 % at elevated temperature from 40°C to 100°C in steps of 15°C is plotted in Figure **Error! No text of specified style in document.**.5. There is significant variation in viscosity at lower temperatures but at higher temperature all the contamination converges with minor variation in viscosity for all contamination percentage.

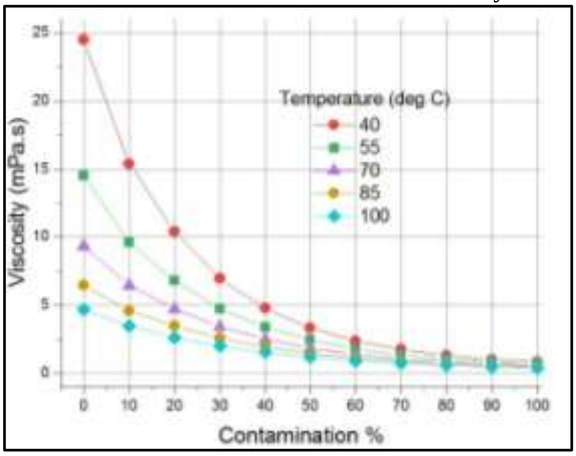


Figure **Error! No text of specified style in document.**.1 Viscosity w.r.t elevated temperature for all Contamination percent

IV. DISCUSSION

a. Theoretical prediction of viscosity

The experimental results of viscosity were compared with calculated values from equations obtained by ‘Grunberg Nissan equation’, ‘Kendall Monroe equation’ and 'Arrhenius equation’.

Cont. %	Experimental μ (mPa.s)	Calculated μ(mPa.s)	
		Grunberg-Nissan/ Arrhenius equation	Kendall-Monroe equation
10	27.23	30.14	58.74
20	17.48	20.84	57.97
30	11.09	14.41	55.18
40	7.27	9.96	51.19
50	4.84	6.89	46.27
60	3.33	4.76	40.53
70	2.37	3.29	33.92
80	1.73	2.28	26.31
90	1.33	1.57	17.16

Table 3. Measured and calculated values of viscosity using theoretical equations

From Table 3 it is observed that the predicted values of viscosity using theoretical equations is not able to correlate the experimental results. The error for the low level of contaminations is high and the error percentage increases with increase in contamination. The deviation from the theoretical models is an indicative of the mixture is dissimilar in chemical structure, non-polar and non- associated.

b. lnμ Vs Contamination %

Previously in figure 1 it was observed that the viscosity decreases exponentially with contamination at a given temperature and figure 2 showed the same trend for different temperature ranges. Natural logarithmic Viscosity with contamination and temperature shows a linear behaviour as presented in figure 4. Assuming it to be linear behaviour, further study is undertaken by using linear regression analysis to estimate the relationship. Regression analysis is carried out to estimate the relationship between a dependent variable "Viscosity" and the independent variables "Contamination percentage and Temperature".

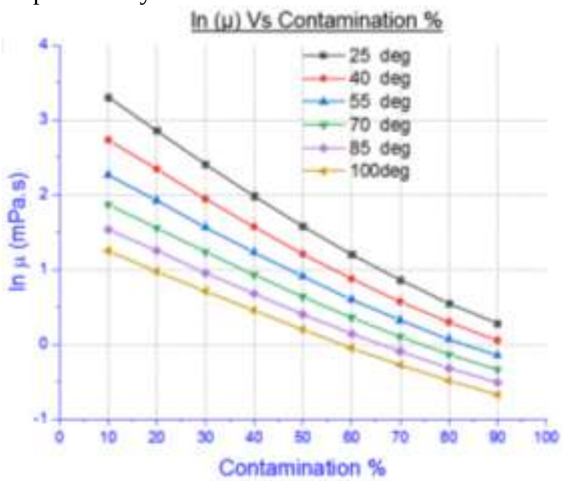


Figure 4. Graph for Natural logarithmic Viscosity with contamination percentage at different temperatures

c. Regression Analysis

Regression analysis is performed on the experimental data to determine the relationships of different parameter under study.

$\mu_{mix} = Pe^{qC}$ for a given temperature
$\mu_{mix} = Re^{sT}$ for a given contamination

Where,

μ_{mix} = Dynamic viscosity of the oil fuel mixture in 'mPa.s'
T = Temperature in degrees
C = Contamination percentage.
P, R = Fitting constants
q, s = Slope

Decrease in viscosity is observed with increase in contamination and temperature. The decreasing trend of viscosity is unique for a given contamination and temperature ranges. Prediction of viscosity for different contamination and temperature is attempted through regression analysis.

$$\mu_{mix} = f(T, C)$$

Experiments data for viscosity at deferent contaminations from 0 -100% in steps of 10% and temperature range from 25 to 100deg C in steps of 15deg C is used for performing the regression analysis. The input parameters for the analysis were contamination and temperature and the output parameter is the natural logarithm of viscosity.

$$\text{Ln}\,\mu = \alpha + \beta * C + \delta * T$$

α, β & δ = constants

The constants determined with an R^2 of 0.99 and the value is noted in table 4.

Constants	α	β	δ
	3.377041	-0.02847	-0.01752

Table 4. Equation for the Dynamic Viscosity of oil fuel contamination liquid mixture

d. Prediction of viscosity

Error percentage and standard deviation for the viscosity values achieved by the theoretical equation were calculated. The same is compared with the proposed model which is derived from regression analysis and the values are shown in table below.

Parameter	Grunberg-Nissan & Arrhenius Equation (Eq01)	Kendall-Monroe equation (Eq02)	Regression Model (Eq08)
Mean Error Percent	30.1	806	7
Standard Deviation	2.55	40.45	0.35

Table 5. Comparison of MEP and SD for theoretical equations and regression model

e. Experimental Vs Calculated viscosity

Cross plot between the experimental and calculated values by regression analysis for viscosity is shown in fig (5). The diagonal line indicates that the measured value is the same as that of calculated values of viscosity. The result indicated that empirical correlation derived by regression analysis for viscosity with temperature and contamination percentage can estimated the measured values with standard deviation of 0.35.

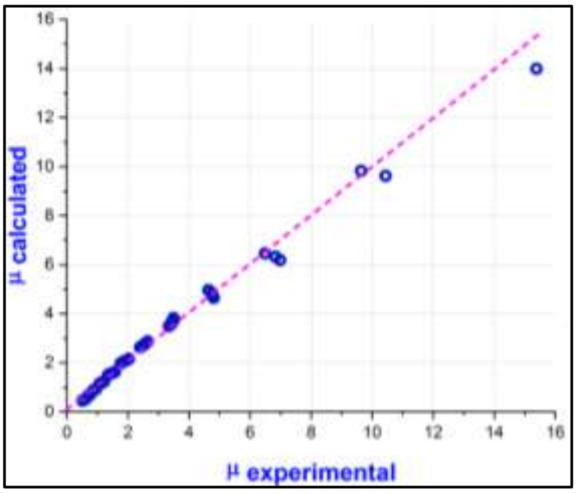


Figure 5. Plot for Experimental viscosity verses calculated viscosity based on the developed model.

V. CONCLUSION

An experimental investigation was conducted on fuel dilution in engine oil for its effect on viscosity. The study was carried out for different percentage of fuel dilution varying from 0-100% in the steps of 10%. For each percentage of fuel dilution experiments were conducted for different temperatures ranging from 25deg to 100degC in steps of 15 deg C. The experimental results for different contamination were compared with the theoretical equations and the regression analysis approach was used to understand the effect on viscosity due to contamination and temperature. The conclusions of the study are as follows,

- Viscosity decreases exponentially with increase in percentage of the fuel diluted oil at fixed temperature. Similar behaviour was also observed in the literature. The experimental data was fitted graphically with R square value of 0.99 and equation 4 is derived. The constant of the equation is unique for this relationship.
- Experimental investigation of viscosity with temperature showed an exponential decrease for a given fuel dilution percentage. The decay rate has an inverse relationship with fuel dilution percentage. The change in decay rate across the different percentage of fuel dilution is an indicative of deviation from the ideal mixture.
- Prediction of viscosity for binary mixture has been an area of interest. The experimental value of viscosity was compared with the models of 'Grunberg Nissan equation' 'Kendall Monroe equation' and 'Arrhenius equation'. The prediction from the models showed higher error percentage and standard deviation for the mixture under study. This emphasized the need of developing a model through statistical approach.
- Regression analysis tool with a confidence interval of 98% was used to develop equation for predicting viscosity from fuel dilution percentage and temperature. Relation for predicting viscosity was developed having three constants with R square value of 0.99.
- Viscosity prediction through the regression model is compared with experimental data. The error percentage and standard deviation of the regression model is 7 and 0.31 respectively which is significantly lower than the theoretical prediction.
- The developed model has close correlation with the experimental results.

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