INVESTIGATION ON PARAMETERS INFLUENCE FOR INTRINSIC INSTABILITY ANALYSIS OF SOLID PROPELLANT (AP+HTPB+TDI) USING COMPUTATIONAL IMAGE-PROCESSING TECHNIQUE

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The effect of the different mixture in a high volumetric concentration of oxidizer (AP) with least percentage of binder (HTPB+TDI) for improving the propellant burn rate was investigated. The combustion experiment is performed using a window bomb setup and the high-speed camera is utilized to capture the flame images. An image processing approach is used to measure the burn rate and intrinsic instability of flame by discrete wavelet transform method. Region growing algorithm technique is used for image segmentation. The morphological operation is implemented with Euclidean distance measurement for the identification of flame height in configuring with dependent parameters (burning rate, diffusion flame height). The qualitative analysis (signal characterization) and quantitative analysis (mean, kurtosis, skewness, standard deviation and frequency) were used to study the intrinsic instability characteristics of the flame diffusion. A result obtained from the analysis proves that the instability in fuel combustion occurs at higher mix and pressure level.

Keywords: *Solid propellant, Ammonium-per-chlorate, burn rate, HTPB, wavelet transform, statistical analysis.*

1. Introduction

Heterogeneous solid propellant, which contains both oxidizer and fuel, are highly combustible and produce high-temperature gaseous molecules by Beckstead, M.W., Derr, R.L., Price, C.F., (1970)., Vesna Rodic and Miomir Bajlovski, (2006). A fine AP particles exhibit plateau characteristics by Masafumi Tanaka, Yoshinori Nakayama, and Tomonari Yoshioka, (2003). A computer-assisted technique is used to obtain the burn rate and intrinsic instability of the proposed propellant formulation for fuel lean composite propellant by Williams, F. A. (1985). AP /binder ratio is shown in Table 1. The study shows how a lean mixture of the binder into the propellant inclusion alters burn rate characteristics. Then the study carries out the intrinsic instability of flame, by depressurization of varying in cylinder pressure. The proposed architecture of the study system is shown in Fig. 1.

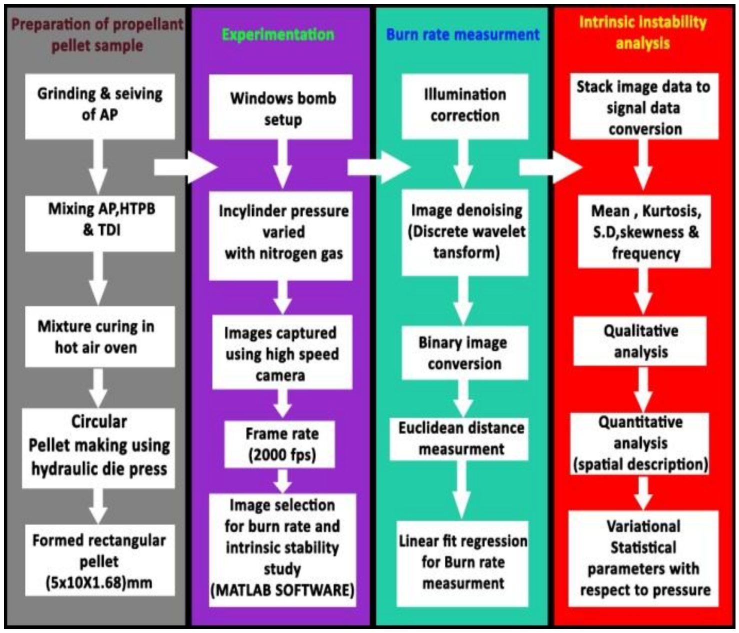


Figure. 1 Proposed plan of the system for the measurement of burning rate

1.1. Origin of the problem and need for research

It is observed the previous study that combustion characteristics of the use of lean fuel mixture based on computer-assisted technique are not so well described. While the existing techniques provide insight into the combustion environment, the burning and instability characteristics of rich fuel mixture but don't provide a clear picture on a validating technique for the characterization of burn rate and intrinsic instability of the flame. Clearly, more diverse computer-assisted techniques are needed to elucidate the mechanisms of composite propellant combustion for lean fuel solid propellant mixture. In particular, direct measurements of the propellant flame structure of sample mixture could give only a drafted view of the propellant characterization. Hence, there is a need to study the solid propellant characterization based on the lean mixture with a computer assisted measurement technique.

1.2. Objective of the work

The proposed approach is to identify that, how the oxidizer influence can modify the burn rate and instability characteristics in a composite solid propellant. This is achieved by statistical validation through computational image processing method to study the effects of lean binder replacement with inclusion modified, AP/Binder (92/08, 94/06, 96/04, 98/02 and pure AP wt. %). The end effects of inclusion content, density, burning rate and an intrinsic instability of the flame are addressed to determine how lean mixture of the binder into the propellant inclusion alters the burn rate characteristics and the instability behavior. The study is to conduct a mathematical model using an image processing technique for the experimentally acquired images in high-speed camera (NX7-S2, USA) to measure the burn rate for the different propellant mix samples and addressing intrinsic instability. The specifications of the High-speed camera is presented in Tab. 1.

Table. 1 Image acquisition parameters of the high-speed camera system.

Parameters	Value
Frame rate (fps)	2000
Electronic shutter (s)	1/100,000
Video duration (s)	6
Total frames	12000
Pixel resolution (mm^2)	0.0978× 0.0978
Focal length (mm)	7

2. Methodology

2.1. Preparation of propellant pellet

AP (an oxidizer) of particle size 63-75μm obtained through planetary ball mill (PULVERI SETTE 5 classic line, Germany), HTPB (fuel binder) and TDI (curing agent) of required amount as shown in Tab. 2. is mixed thoroughly in a beaker and kept in an oven at 303 K for curing for 7 days. Around 1.8 gram of the mixture is taken in a stainless steel die of the circular cross-section of one-inch diameter, kept under hydraulic press at 200 bars for two hours to make pellet as shown in Fig. 2. The pellet sample is prepared with the dimensions of 10 mm× 5 mm× 1.68 mm for five different compositions.

Table. 2 Composition of solid Propellant samples by weight percentage

Mix no.	% Binder	Density (g/cm^3)	% AP	%HTPB	%TDI
1	0	1.95	100	-	-
2	2	1.9294	98	1.88	0.12
3	4	1.9088	96	3.76	0.24
4	6	1.8882	94	5.64	0.36
5	8	1.8676	92	7.52	0.48

Figure. 2 Preparation of propellant pellet samples using die press

2.2. Experimentation

Fig. 3. shows the setup consisting of a cylindrical chamber pressurized with nitrogen (purge gas) and two optical windows, one for light illumination and other for capturing the combustion photography with a high-speed camera of 2000 frames per second Jayaraman (2008) [5]. The sample is placed in-between the two electrodes and nichrome wire placed on the top of the pellet, then connected to two electrodes, DC power supply is used for ignition. Figure. 4 shows sample images of combustion

photography. The experiment conducted for five proportions at the pressure range of 20, 35, 50, 70 and100 bar respectively.

2.3. Image processing approach

Fig. 5. shows the image de-noising using discrete wavelet transform. The proposed measurement system of flame burn rate and instability initializes with contrast enhancement and SWT. The segmentation process is shown in Fig. 6. where the ROI is the crucial step in the analysis of flame based propellant images. The accuracy of the segmentation depends on the ROI from the images. Segmentation of propellant images refers to segmenting the regions in the image that contains only the propellant samples for the burn rate measurement.

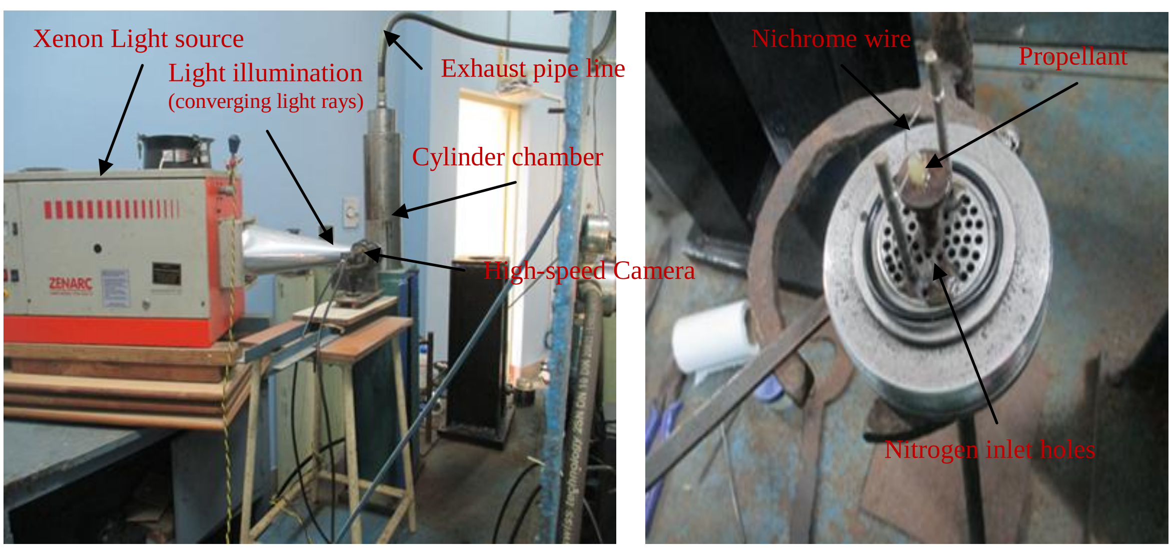


Figure. 3 Experimental view of the window bomb set-up

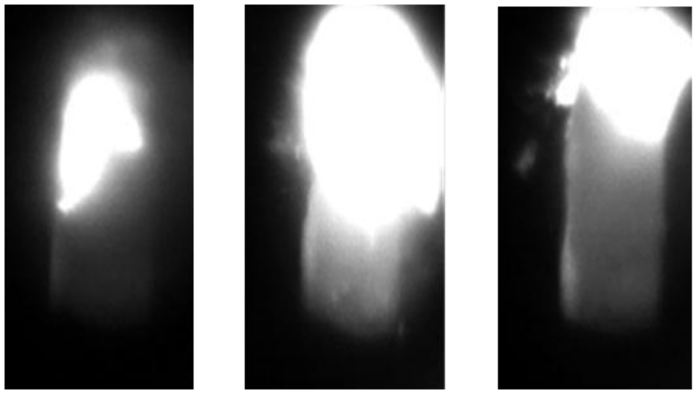


Figure. 4 Sample images of combustion photography for different pressure

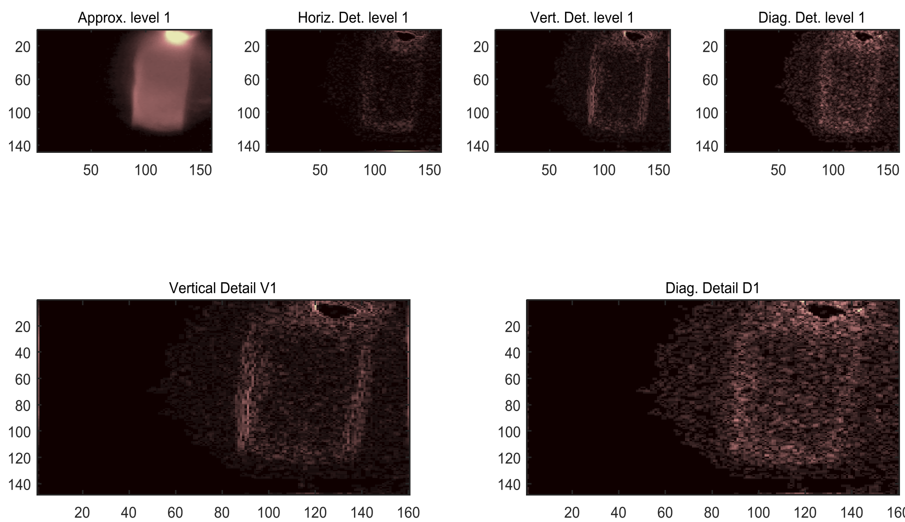
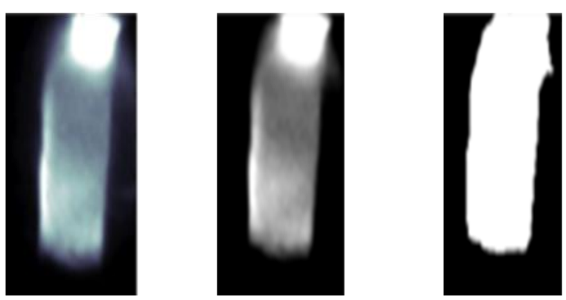


Figure. 5 Image de-noising using discrete wavelet transform



Original De-noised image Binary image

Figure. 6 Segmentation process using region growing algorithm

The Euclidean distance is the pixel distance between two points in Euclidean space. The analysis is carried out to predict the exact pixel distance to nominal distance of the burning propellant images. It was observed that the behavior of Euclidean distance becomes more useful with increased number of samples by Shu-yin Xia, Zhong-yang Xiong, Yue-guo, Luo Wei-Xu, Guang-hua Zhang, (2015). In the Euclidean plane, if p = (p_1, p_2) and q = (q_1, q_2) then the distance is given by Reddy, Busireddy, Nagarjuna, and Siba Udgata. K. (2013).

$$d\ (p, q) = \sqrt{(q_1 - p_1)^2 (q_2 - p_2)^2} \quad ....[1]$$

This method is used to detect the segmented propellant height in terms of pixel distance converted to the actual distance based on the Euclidean plane. Thus the reduction in the propellant sample with respect to the burn rate can be measured.

2.4. Intrinsic instability analysis

Intrinsic instability study details the mechanism of flame characterization to weak disturbances. Under oxidizer rich and at higher pressures say 100 bar, intrinsic instability is noticed in the type of statistical parameters derived from the combustion images for flame growth, whose position oscillates laterally about the mid fuel binder layer. Fig. 8. illustrates the main parameters for the image data acquisition for the qualitative and quantitative analysis of the propellant combustion.

3. Results and discussion

3.1. Burn Rate Measurement

A linear fit curve regression model has been developed using MATLAB software, where the slope equation is determined to be the burn rate value. The burn rate regression graph for varying in-cylinder pressure (20-100) bar with different binder mix samples and pure AP is shown in Fig. 7.

3.2. Instability characteristics

Under depressurization for various in cylinder pressure and different spectral characteristics for instability burning of flame are obtained as shown in Fig. 8 (a-c). and the spatial characteristics are shown in Fig. 8 (d-h). The present study in this part is to illustrate significant differences in flames when the fuel is burnt under rapid depressurization of in-cylinder pressure. The distribution of parameters is obtained as color contour maps in order to visualize possible flame patterns. Pure AP sample is compared to the mixed binder ones taken into account underlying in cylinder pressures under rapid depressurization. The flame parameters with a statistical definition for flame brightness, fluctuation amplitude, and distribution symmetry and oscillation frequency are shown in Table. 3. The brightest area, composed of values above 180 gray units, extends and increases with fuel binder addition due to the compensative fuel mix with the oxidizer content (see Table 2). This effect has the same opinion with previous experimental results Lu, G., Yan, Y., Colechin, M., Hill, R. (2006)., Lu, G., Yan, Y., Cornwell, S., Whitehouse, M., Riley, G. (2008).

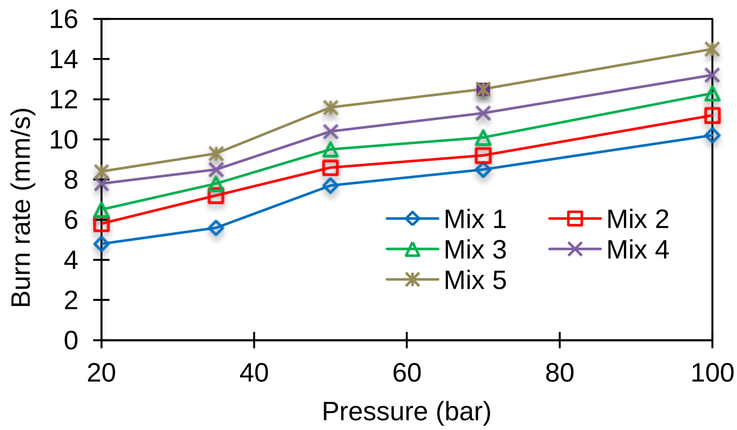


Figure. 7 Burn rate vs. pressure

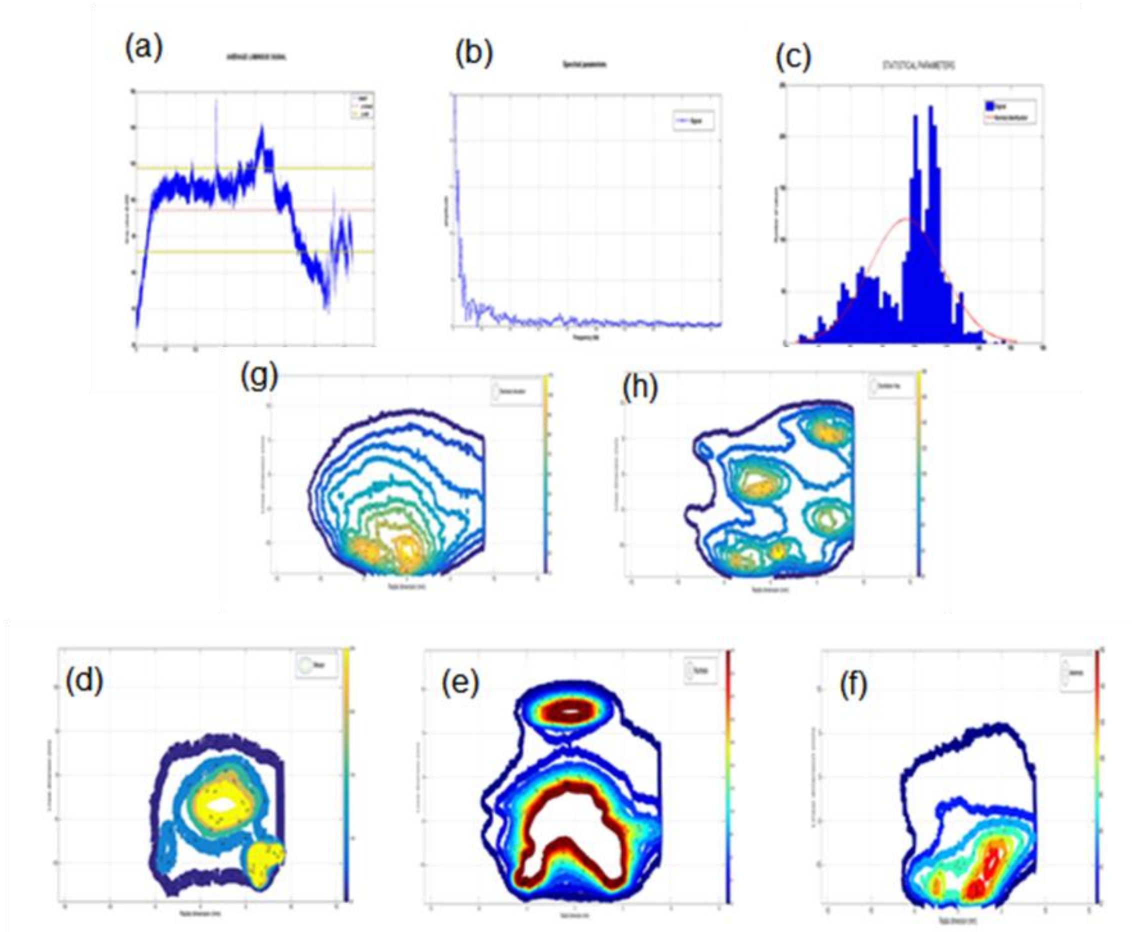


Figure. 8 Qualitative and quantitative analysis of the propellant combustion extracted from the image. (a) Signal characterization, (b) Power spectral density, (c) Histogram plot, (d) Mean, (e) Kurtosis,(f) Skewness (g) Standard Deviation, (h) Oscillation frequency

Table. 3 Combustion Flame parameters with statistical definition

Signal characterization	Statistical/spectral parameter	Mathematical expression
Flame brightness	Mean value ($\bar{x}$)	$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$
Fluctuation amplitude	Standard deviation (σ)	$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$
Distribution symmetry	Kurtosis(k) and Skewness (s)	$y = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^m}{\sigma^m}$
Oscillation frequency	Flicker(F)	$F = \frac{\sum_{k=0}^{N-1}\lvert X(f_k)\rvert . f_k}{\sum_{k=0}^{N-1}\lvert X(f_k)\rvert}$

Instability of flame mostly depends on the addition of binder fuel content on the oxidizer, which causes the flame to detonate on ignition. On the depressurization condition, the flame starts to oscillate highly for the binder mixed fuels, whereas the pure AP oxidizer proves a stable burning. No important increments are observed in the pure AP and their values are relatively even or even to some extent lower with flicker rise. The Quantitative plots for mean, standard deviation, skewness, Frequency, and kurtosis is presented in Fig. 9 (a-e).

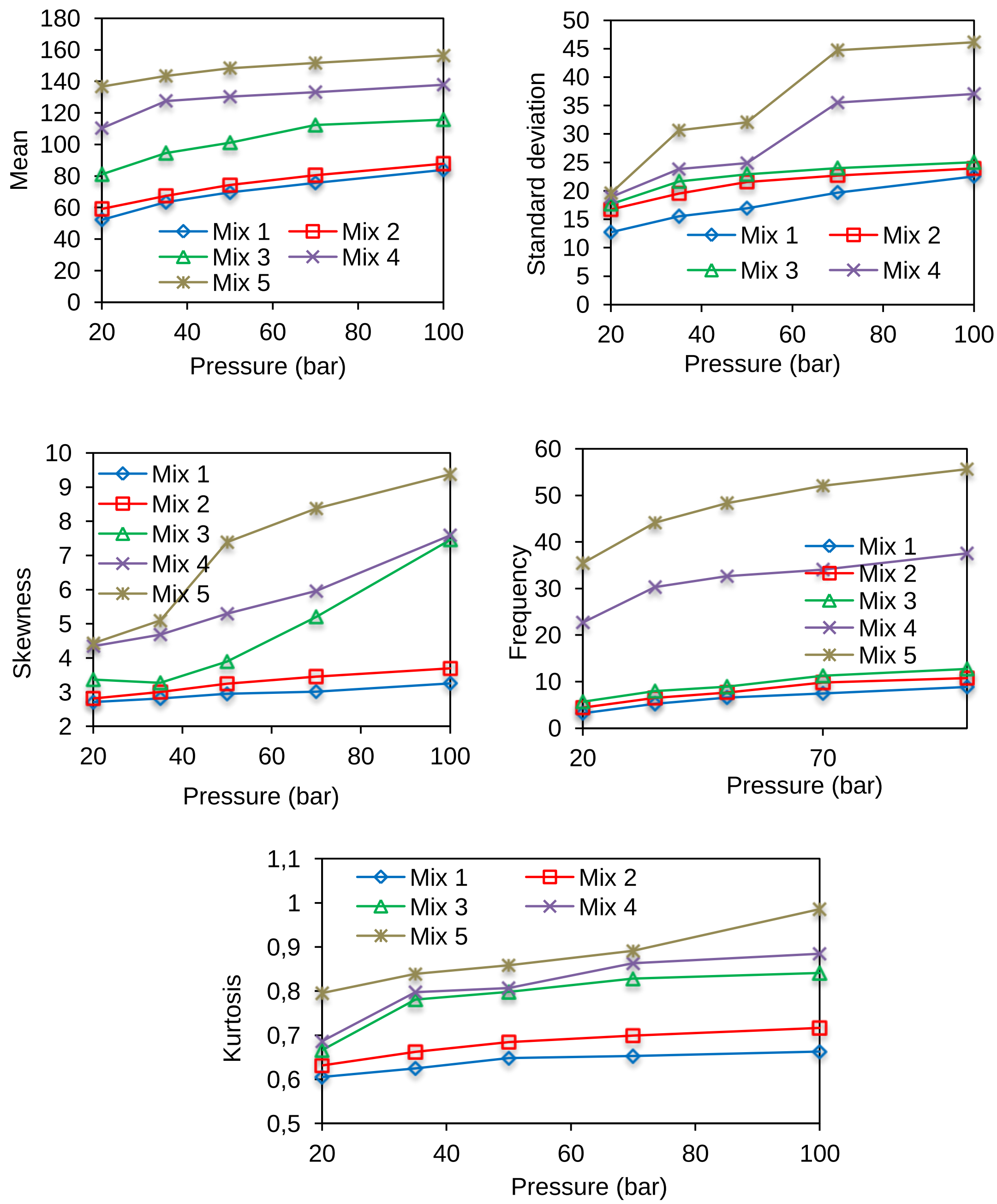


Figure. 9 Variation of statistical and spectral parameters for different pressure values, (a) Pressure vs. Mean. (b) Pressure vs. Standard deviation, (c) Pressure vs. skewness, (d) Pressure vs. Frequency, (e) Pressure vs. kurtosis

4. Conclusion

An experimental result reveals that oxidizer rich solid propellants exhibit an increase in burn rate by adding few percentages of fuel binder (HTPB). At the pressure 100 bar, Mix 5-burn rate (14.5 mm/sec) is higher than the burn rate Mix 1-(10.2 mm/sec). Intrinsic instability of flame has possessed a statistical characterization of the flame front. The physical characteristics of the flame were studied by wavelet and image processing techniques. The increase in cylinder pressure increases burn rate, also fuel binder addition shows growth in flame brightness from which statistical and spectral parameters were obtained. The quantitative and qualitative results show the flame stability which proves that the instability in fuel combustion occurs at higher mixes and pressure level.

Nomenclature

AP -	ammonium perchlorate
HTPB-	Hydroxyl terminated polybutadiene
TDI -	Toluene diisocyanate
S.D -	Standard deviation
SWT -	Stationary wavelet transform
ROI-	Region of interest
DC-	Direct current

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Submitted: 19.11.2016
Revised: 18.03.2017
Accepted: 03.04.2017