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1. **Project details**
   - **a.** *Title*: *Composition analysis of different types of pellets/briquettes received from unknown sources*
   - **b.** *Institute*: *Sardar Swaran Singh National Institute of Bio-Energy, Kapurthala*

2. **Aim / Objectives:**

1. To collect and analyze raw agro residue viz. paddy straw and other residual biomass, of northern India (Punjab and Haryana) for composition analysis (proximate and ultimate analysis).

2. To prepare and analyze pellets generated with varying composition, % of paddy straw content varying from 0-100%.

3. To identify compositional arrangement of pellets using database generated from raw agro waste using proximate, ultimate and thermo gravimetric analysis.

4. To analyze the database by using appropriate software and development of a methodology for estimation of paddy content in unknown pellets by curve fitting and linear equations.

3. **Executive Summary (*One page*):**

The NMB2 project titled "Composition analysis of different types of pellets/briquettes received from unknown sources" aimed to develop a method for estimating the percentage of paddy straw in unknown biomass pellet samples. This is critically important, as farm fires in and around Punjab are primarily due to open burning of paddy straw. To promote utilization of paddy straw in thermal power plants via co-firing with coal, it is essential to ensure that the pellets contain at least 50% or more paddy straw.
The project focused on identifying a biomarker that is highly specific to paddy straw and is present in significantly lower concentrations in other agro-residues or materials often blended into pellets. Based on proximate, ultimate, and heating value analyses of agro-residues from the Punjab region, ash content was initially identified as a suitable biomarker. Paddy straw typically contains ~20% ash, the highest among agro-residues in the region.

Methodology Overview

Problem Definition:
Consider a mixture of three components A, B, and C, with their proportions summing to 100%. The biomarker concentrations of pure A, B, and C are known, and the biomarker concentration of the mixture is experimentally measured. The goal is to determine the percentage of A in the mixture.

Relationship Formulation:

$S_m = y_A \cdot S_A + y_B \cdot S_B + y_C \cdot S_C$ (1)

where y_A, y_B and y_C represent the fractional contents of A, B, and C in the mixture, respectively.

The constraint is $y_A + y_B + y_C = 1$

Regression Model Setup:

Data is generated using:

a) Synthetic mixtures or

b) Experimental mixtures

Biomarker concentrations are either calculated using the above equation or determined experimentally. A linear regression of the form $y_A = \beta_0 + \beta_1 \cdot S_m$ where β_0 is the intercept, β_1 is the slope, is then fitted to predict the paddy content from measured biomarker values.

Challenges Faced

Initially, 108 experiments were performed using mixtures such as PR126+mustard+sawdust, PR126+wheat+mustard+maize+sweet sorghum, and PR126+mustard+pressmud. However:

1. Pressmud, a common pellet ingredient, has extremely high ash content (>40%), rendering ash an unreliable biomarker for detecting paddy straw when it is mixed with paddy straw for making mixed pellets supplied to thermal power plants. Other potential biomarkers such as fluoride, bromide, and phosphate were tested, but they were more influenced by soil and water quality than by the intrinsic characteristics of paddy straw. A second round of 126 experiments involving PR126+wheat+mustard+maize+pressmud mixtures yielded inconsistent and region-specific results.

2. The addition of any new biomass type required a complete re-evaluation of existing mixtures, leading to a rapid increase in the number of possible combinations. As more biomass types would be introduced by vendors, the experimental workload would grow substantially, making it impractical to test every combination individually.

Proportionate Study and Silica as a Biomarker

To overcome the limitations, a proportionate analysis approach was adopted. This assumes that the properties (biomarker concentrations) of a pellet are linearly additive based on composition—reasonable since pelletization is a physical process and does not alter chemical properties. This approach used vendor-declared biomass compositions and bypassed the need for exhaustive experimental mixing.

Silica emerged as a promising biomarker—present in paddy straw at 120–140 g/kg, which is 4–5 times higher than in other residues and additives like pressmud.

Observation

An inter-lab validation exercise was conducted between CIRCOT Mumbai, NIBE Kapurthala, and PAU Ludhiana. Unknown pellet and powder samples were exchanged. NIBE used silica, while CIRCOT used biomarkers like manganese to estimate paddy content.

For pellet samples received by NIBE from PAU and CIRCOT, three replicates testing were performed. For pellets received from CIRCOT, the % difference (error) between actual value of paddy % and calculated value of paddy % is low for lower paddy % and higher for higher paddy %. For paddy % of 0, 20, 70, 80, 90 and 100, the % change was 7, 32, 32.26, 38.16, 55.52% and 56.1%. For pellets received from PAU, the trend was opposite as for paddy % of 60, 80 and 90, the % difference was 87.13, 54.93, and 43.38. For powdered samples received from CIRCOT, the % difference (error) between actual value of paddy % and calculated value of paddy % is low for middle paddy % and

higher for higher/lower paddy %. For paddy % of 30, 50, 60, 75 and 85, the % change was 57.77, 19.08, 2.79, 9.03, and 24.77 For powdered samples received from PAU, for mixtures containing paddy straw and mustard straw, the % difference was very low i.e. ~5-6%. However, for powdered samples received from PAU that was a mixture of paddy straw and cotton stalk was extremely high i.e. 33 - 100%. For powdered samples received from NETRA, the % percentage difference between actual and calculated paddy straw % was <5%.

Inter-Laboratory Validation and Limitations Key issues observed:
Pellets:
1. Biomass input during palletization varies widely across pellets due to nonhomogeneous nature of the powdered samples.
2. To counter non-uniformity, multiple pellets were ground and sampled. Still, 0.5 g sample size in IC (ion chromatography) limited representativeness.
3. Dust and sand contamination, both rich in silica, could artificially inflate silica readings, skewing paddy estimates.

Powdered Samples:
1. More controlled than pellets, but still prone to sampling errors.
2. Sand/dust contamination again distorted silica levels.
3. Inaccurate paddy estimates could result from poor sample representativeness.

Key Conclusions
1. Silica, while effective, is sensitive to environmental contamination and should be used in conjunction with other parameters like ash content, manganese, and heating value.
2***. Vendors could manipulate silica or other biomarkers (e.g., by adding sand), so cross-checking multiple parameters is essential. Therefore it is suggested that in addition to silica, other parameters should also be observed and taken into consideration such as ash content, Manganese (or any other biomarker concentration), heating value, etc. A Specific limit may be set for pellets with more that 50% paddy contents with respect to the stated limit of these parameters.***
3. A comprehensive protocol must be developed.

4. Scope for further work

A project has been submitted to CPRI titled "Comprehensive biomass collection and analysis from selective paddy-growing regions of India and quantification of paddy straw content in mixed feed biomass pellets" covering the future scope of work and it has undergone presentation to the SCRD. The project proposal involves:

1. Collection & Analysis of samples from more regions: Sample raw agro-residues from major paddy-producing states (Punjab, Haryana, UP, Rajasthan, Uttarakhand, HP, MP, Chhattisgarh, Odisha, Andhra Pradesh). Analyze for proximate values, anions (F^-, Br^-, SO_4^{2-}, Cl^-, PO_4^{3-}), cations (K^+, Na^+, Mg^{2+}), transition metals (Cu, Ni, Zn), and silicates, total ash, moisture content, volatile matter and heating values.
2. Biomarker Identification for a specific region: Identify region-specific biomarkers with significantly higher levels in paddy straw compared to other residues.
3. Proportionate Study: Conduct proportionate studies using selected biomarkers with 4–5 biomass species to understand concentration behavior in mixtures.

4. Database & Model Development: Analyze data to derive linear equations for estimating paddy content based on biomarker concentration.
5. Testing & Validation: Interlaboratory validation of results will be done to test the efficacy of the model wherein representative biomass and pellet samples will be shared with laboratories to cross-check results, ensuring reproducibility and robustness.

5. Benefits visualized

A validated region-specific biomass database.
Predictive models and SOPs for paddy quantification.
Mixture Composition Recommendations - %Mix with different biomass in different regions to resemble coal
Technical recommendations for policy and industry.