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INTEGRATED FACTORIAL DESIGN AND POROUS MEDIA CFD FOR RICE HUSK DRYING

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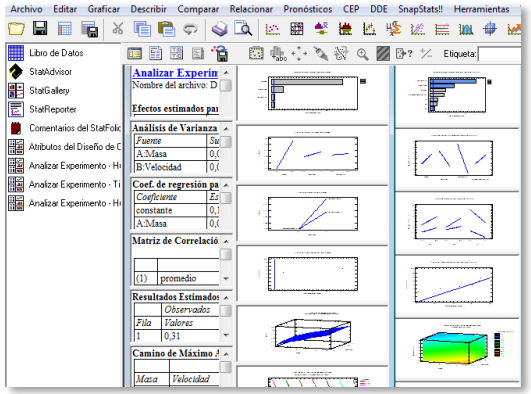
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Introduction

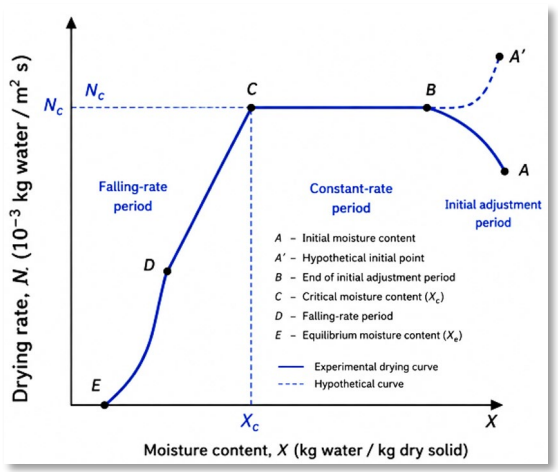
Rice Husks

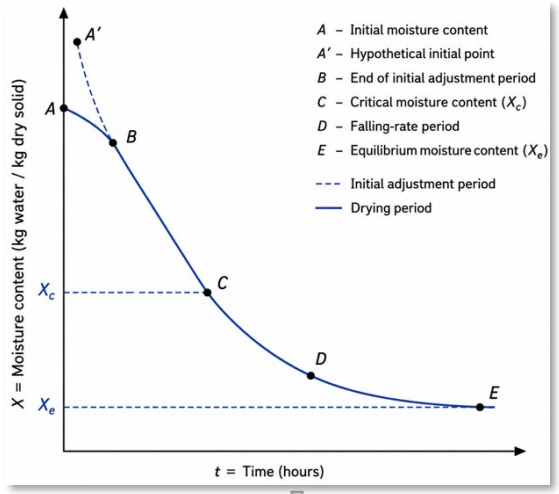


DOE

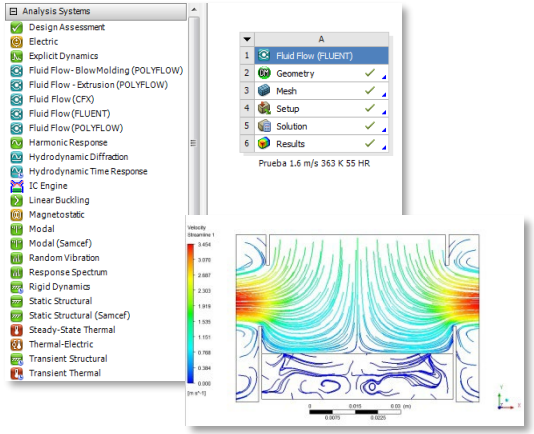


Drying process



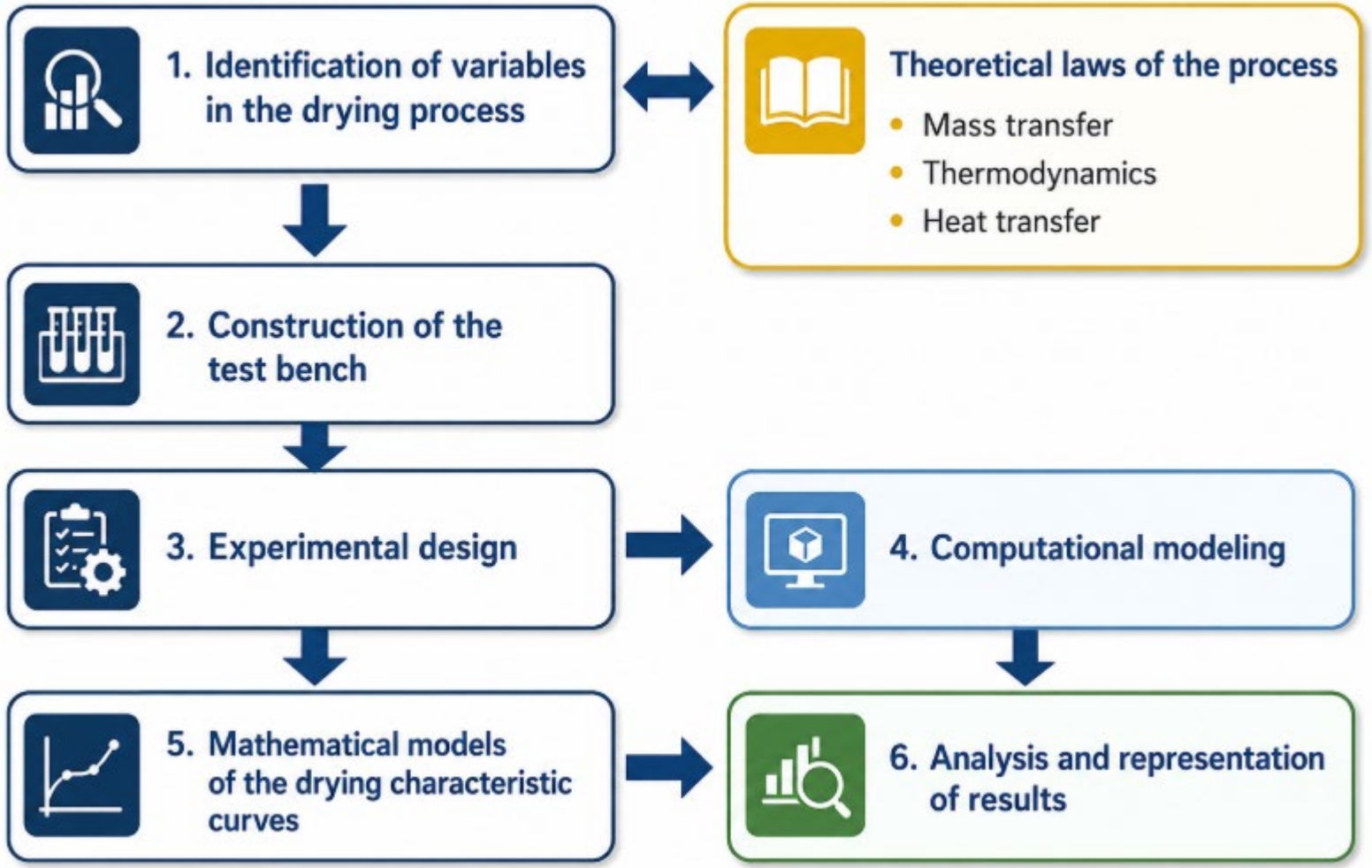


CFD



Solid fuel

Methodology



Methodology

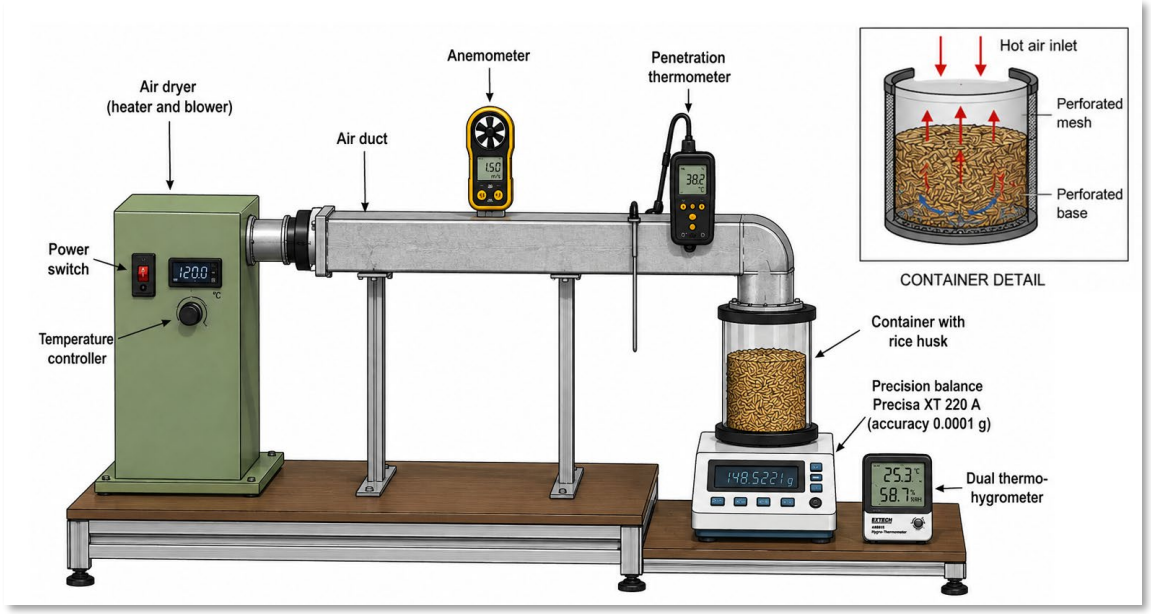
Experimental factors and levels.

Factor	Variables	Low (-1)	High (+1)	Units
A	Sample Mass (SM)	3.0	4.0	g
B	Air Velocity (AV)	0.8	1.6	$m \cdot s^{-1}$
C	Drying Temperature (DT)	363	383	K
D	Relative Humidity (RH)	55	80	%

Response variables for the experiment.

Response variables	Units
Equilibrium Moisture Content (EMC)	g H2O
Equilibrium Drying Time (EDT)	min

Experimental Test Bench



Results

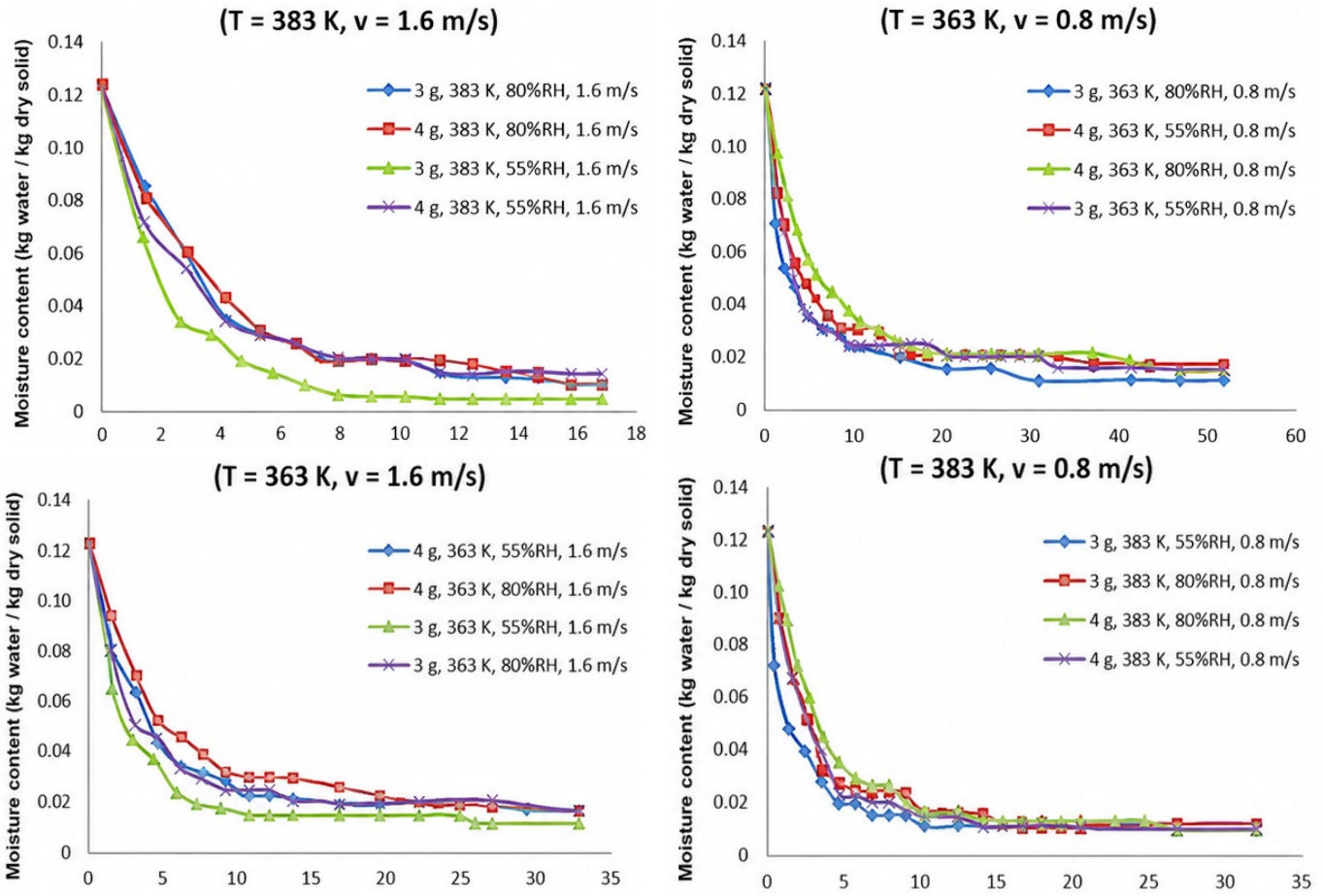
Combined ANOVA Results.

Response	Source	Sum of Squares	df	Mean Square	F-ratio	P-value
EDT	A: (SM)	258.781	1	258.781	78.12	0
	B: (AV)	603.781	1	603.781	182.27	0
	C: (DT)	2194.53	1	2194.53	662.5	0
	D: (RH)	215.281	1	215.281	64.99	0
	AB	22.7813	1	22.7813	6.88	0.0149
	AD	57.7813	1	57.7813	17.44	0.0003
	BC	63.2813	1	63.2813	19.1	0.0002
	Error	79.5	24	3.3125	—	—
	Corrected Total	3495.72	31	—	—	—
EMC	A: (SM)	0.0693781	1	0.0693781	2640.65	0
	B: (AV)	0.00195312	1	0.00195312	74.34	0
	C: (DT)	0.000153125	1	0.000153125	5.83	0.0228
	BC	0.000153125	1	0.000153125	5.83	0.0228
	Error	0.000709375	27	2.62731E-05	—	—
	Corrected Total	0.0723469	31	—	—	—

Model adequacy.

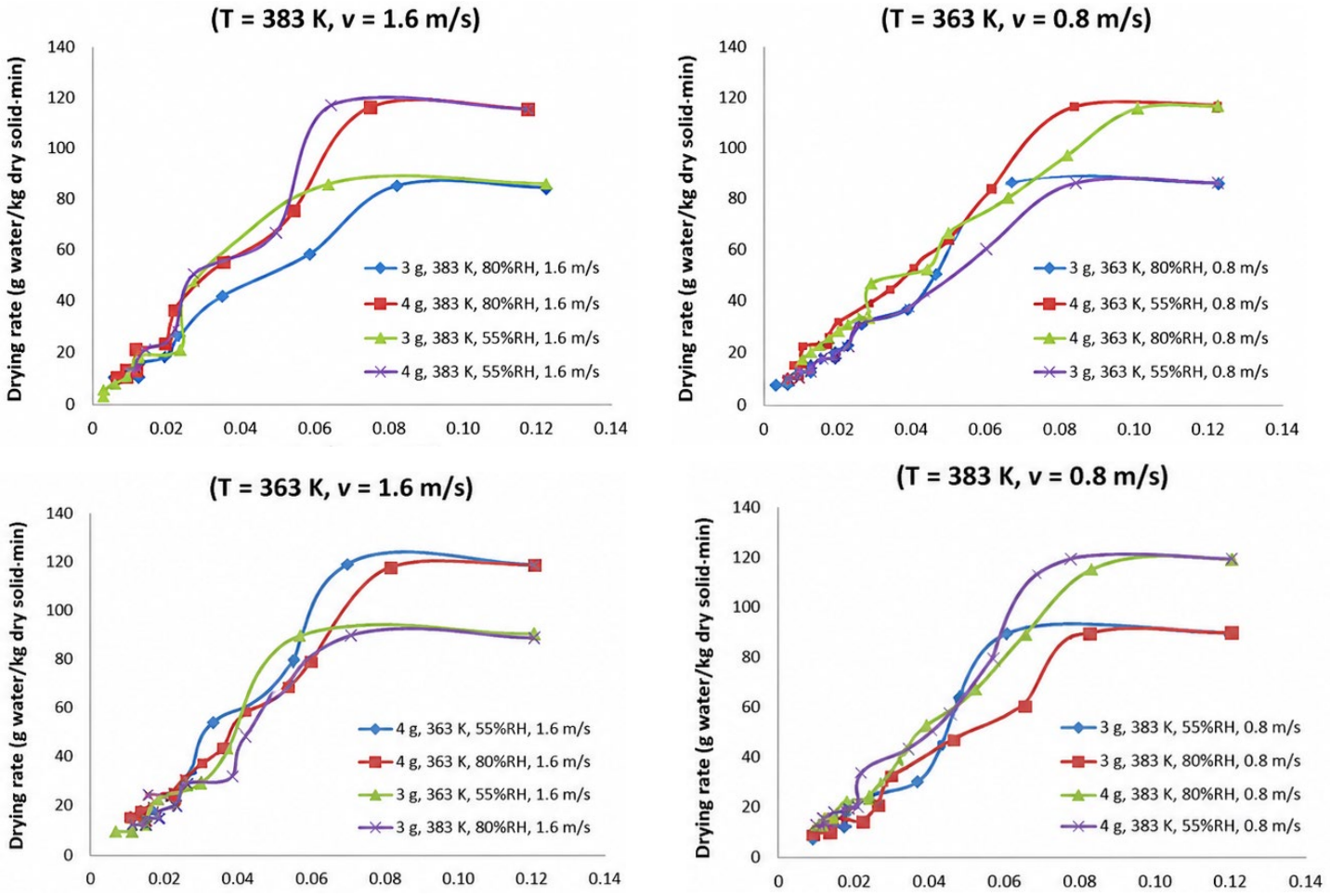
Statistical indicator	EDT	EMC
R^2	97.73%	99.02%
Adjusted R^2	97.06%	98.87%
Standard error	1.82003	0.0051273
Mean absolute error	1.2734	0.00443359
Durbin–Watson statistic	1.52668	2.47137
P-value (DW)	0.092	0.8956
Residual autocorrelation, lag 1	0.226906	−0.25234

Results



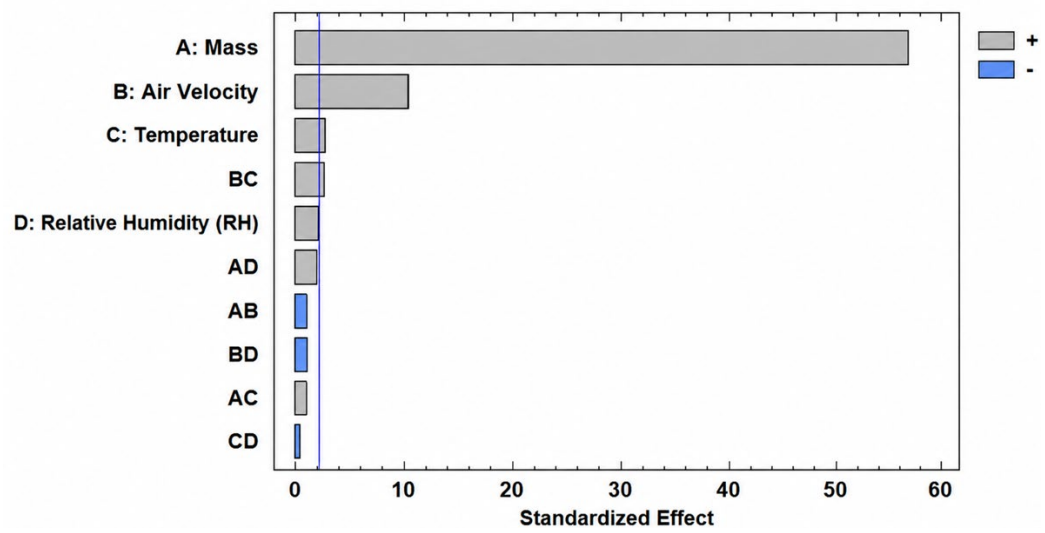
Moisture Content versus Time

Results

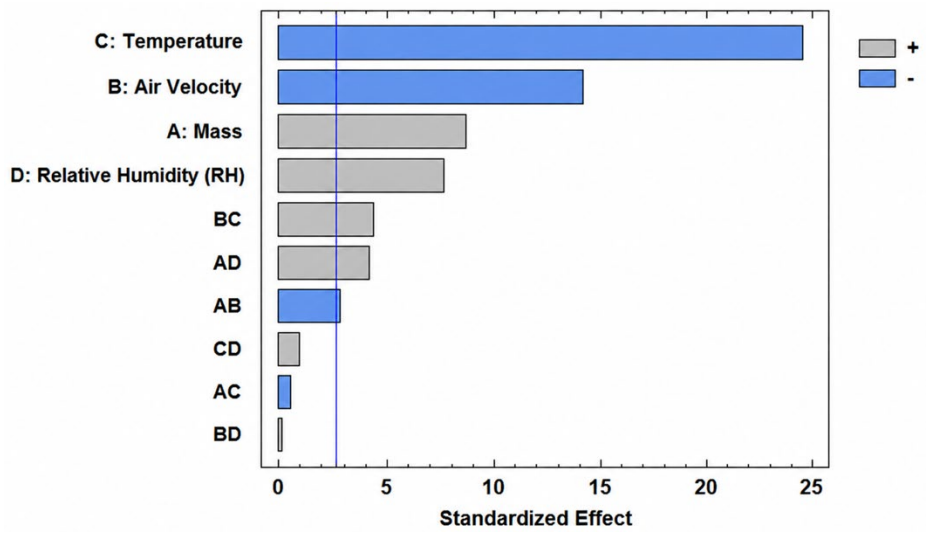


Drying Rate versus Moisture Content

Results

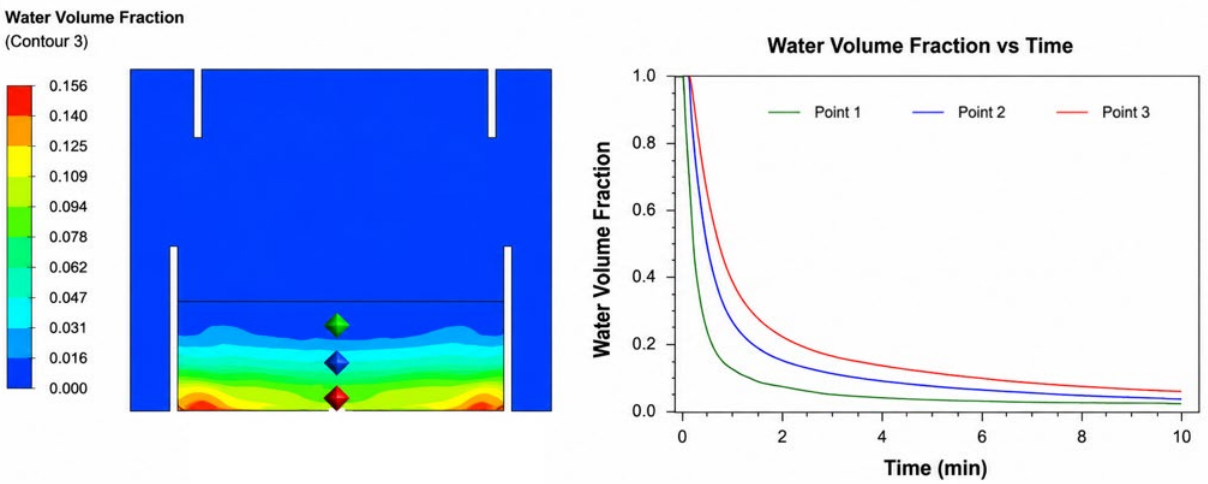


Pareto Chart of Standardized Effects for Equilibrium Moisture Response

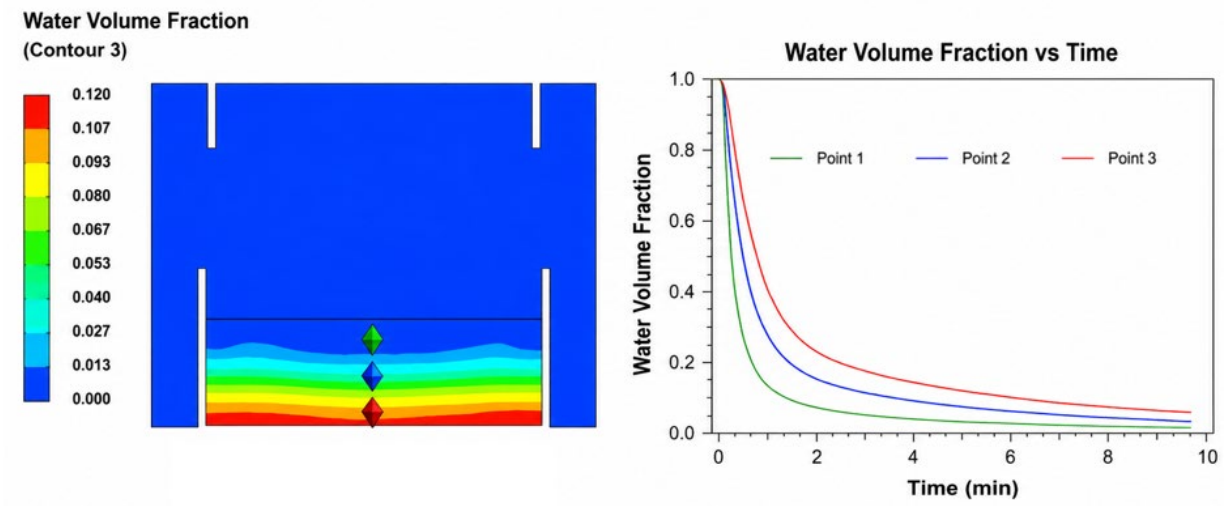


Pareto Chart of Standardized Effects for Equilibrium Drying Time

Results

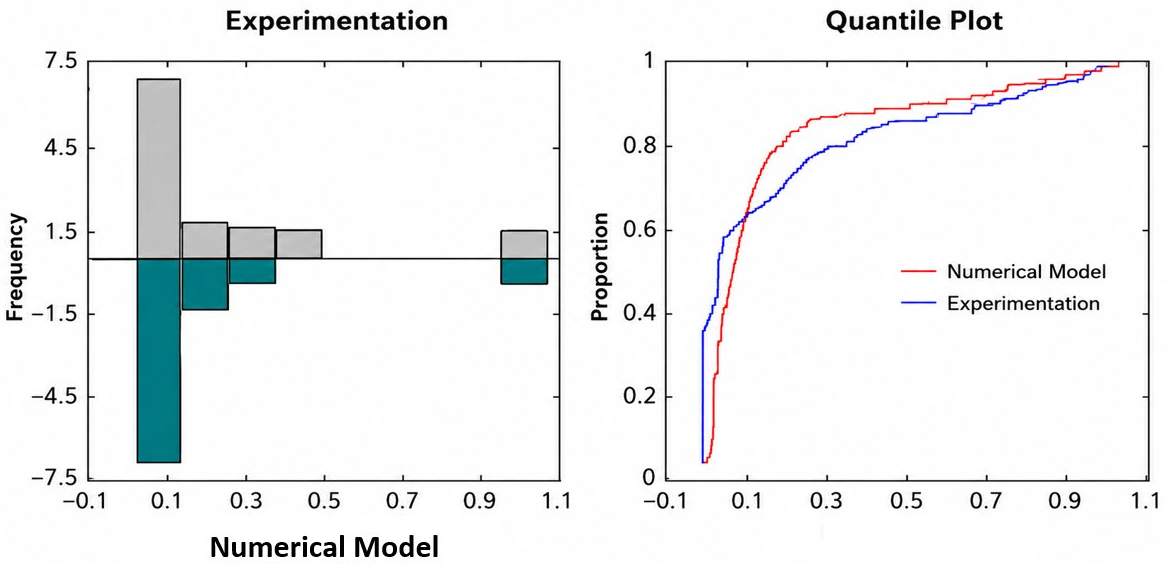


Volume Fraction at 1.6 m/s, 383 K, 80% RH

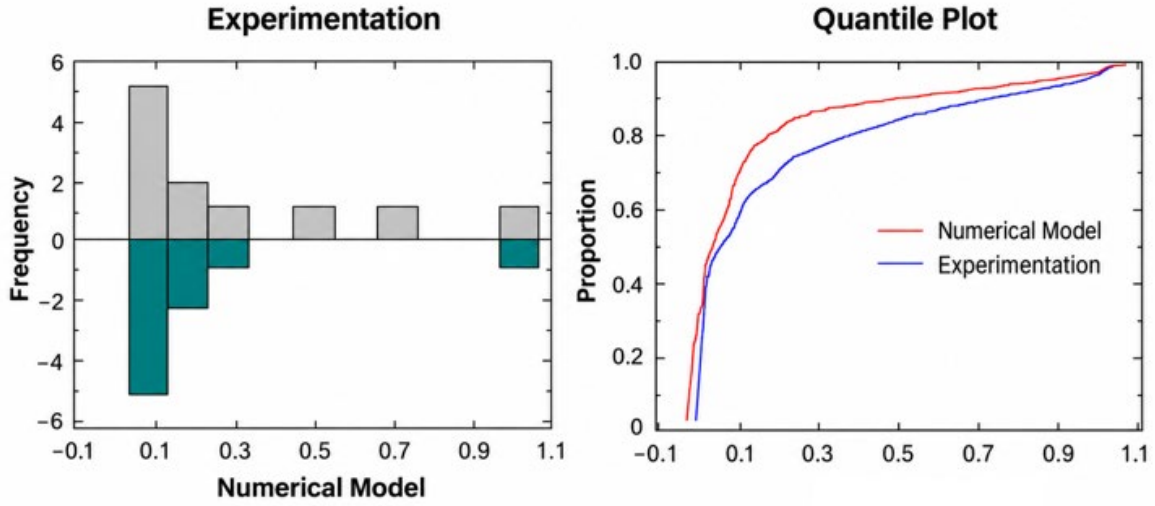


Volume Fraction at 1.6 m/s, 363 K, 55% RH

Results



Comparison of Experimental and Numerical Results for 1.6 m/s, 363 K, 55% RH (Histogram and Quantile–Quantile Plot)



Comparison of Experimental and Numerical Results for 1.6 m/s, 383 K, 80% RH (Histogram and Quantile–Quantile Plot)

Conclusions

- This work successfully demonstrated the feasibility of integrating a FFDOE with PMCFD to investigate the convective drying of rice husk. The combined methodology enabled both the statistical identification of the most influential operating variables and the physical interpretation of the CHaMT mechanisms governing biomass drying.
- Experimental results confirmed that DT and AV significantly enhanced moisture removal and reduced EDT. In contrast, higher SM and RH delayed the drying process due to the reduced moisture transfer driving force and the larger amount of water that had to be removed.
- The factorial analysis showed that SM, AV, DT, and the interaction between AV and DT were the statistically significant effects influencing EMC, whereas most main factors also significantly affected EDT. These findings demonstrate the importance of simultaneously considering operating variables and their interactions during dryer optimization.
- The CFD simulations accurately reproduced the temporal evolution of moisture transport within the porous rice husk bed. Numerical predictions showed that higher temperatures and airflow velocities promoted more uniform moisture removal and shorter drying times, while higher relative humidity slowed evaporation.
- Validation against experimental measurements demonstrated good agreement between both approaches, with average deviations of 4.36% and 8.65% under the two representative operating conditions, confirming the robustness and predictive capability of the proposed PMCFD model.