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THE COMPOSITION OF SOLID PROPELLANT IN MODEL ROCKETS AND ITS EFFECT ON FLIGHT PERFORMANCE: A COMPARATIVE STUDY OF BIOMASS CATALYSIS AND GRAIN GEOMETRY

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Abstract. This paper investigates the influence of solid-propellant composition on the flight performance of model rockets from two complementary perspectives: chemical catalysis and propellant-grain geometry. The conventional potassium nitrate–sugar (KNSU/KNSB) formulation is typically catalyzed with iron(III) oxide (Fe_2O_3); however, this study examines tobacco ash, a low-cost, waste-derived biomass material containing calcium carbonate ($CaCO_3$), potassium carbonate (K_2CO_3), and trace metal oxides, as a potentially resource-efficient alternative. In addition, the internal grain port was formed in a star-shaped configuration rather than the conventional circular geometry, allowing an assessment of how a larger initial burning-surface area affects thrust development. Experimental data obtained through static-fire testing and flight telemetry indicate that the incorporation of tobacco ash was associated with higher measured burn-rate and specific-impulse values than those recorded for the standard and Fe_2O_3-catalyzed formulations. The star-shaped port geometry also produced an earlier and higher thrust peak owing to its larger initial perimeter. Collectively, these findings suggest that biomass-derived additives and grain-geometry optimization may represent useful directions for further research on model-rocket motor performance.

Keywords: solid propellant, potassium nitrate, tobacco ash, catalyst, star-shaped grain, specific impulse, burn rate.

Annotatsiya. Ushbu maqolada qattiq yoqilg‘i tarkibining model raketalarning parvoz samaradorligiga ta’siri ikki o‘zaro bog‘liq yo‘nalish — kimyoviy kataliz va yoqilg‘i donasi geometriyasi nuqtayi nazaridan tadqiq etilgan. An’anaviy kaliy nitrat–shakar (KNSU/KNSB) tarkibida odatda katalizator sifatida temir(III) oksidi (Fe_2O_3) qo‘llanadi. Mazkur tadqiqotda esa kalsiy karbonat ($CaCO_3$), kaliy karbonat (K_2CO_3) va metall oksidlarining iz miqdorlarini o‘z ichiga olgan, biomassadan hosil bo‘luvchi arzon chiqindi material — tamaki kuli resurslardan samarali foydalanish imkonini beruvchi muqobil qo‘shimcha sifatida o‘rganilgan. Bundan tashqari, yoqilg‘i donasining ichki kanali an’anaviy aylana shakli o‘rniga yulduzsimon shaklda tayyorlanib, boshlang‘ich yonish yuzasining kattalashishi tortish kuchining shakllanishiga qanday ta’sir ko‘rsatishi baholangan. Statik olov sinovlari va parvoz telemetriyasi orqali olingan tajriba ma’lumotlari tamaki kulining qo‘shilishi standart hamda Fe_2O_3 katalizatori qo‘llangan tarkiblarga nisbatan yonish tezligi va solishtirma impulsning yuqoriroq o‘lchangan qiymatlari bilan bog‘liq bo‘lganini ko‘rsatdi. Yulduzsimon kanal geometriyasi ham kattaroq boshlang‘ich perimetr hisobiga tortish kuchining ertaroq va yuqoriroq cho‘qqisini hosil qildi. Umuman olganda, mazkur natijalar biomassadan olinadigan qo‘shimchalar va yoqilg‘i donasi geometriyasini optimallashtirish model raketa dvigatellarining samaradorligini kelgusida tadqiq etish uchun istiqbolli yo‘nalishlar bo‘lishi mumkinligini ko‘rsatadi.

Kalit so‘zlar: qattiq yoqilg‘i, kaliy nitrat, tamaki kuli, katalizator, yulduzsimon yoqilg‘i donasi, solishtirma impuls, yonish tezligi.

Аннотация. В статье исследуется влияние состава твёрдого топлива на лётные характеристики модельных ракет с двух взаимосвязанных позиций: химического катализа и геометрии топливной шашки. В традиционных составах на основе нитрата калия и сахара (KNSU/KNSB) в качестве катализатора обычно применяется оксид железа(III) (Fe_2O_3). В настоящем исследовании в качестве потенциально ресурсосберегающей альтернативы рассматривается табачная зола — недорогой отход биомассы, содержащий карбонат кальция ($CaCO_3$), карбонат калия (K_2CO_3) и следовые количества оксидов металлов. Кроме того, внутренний канал топливной шашки был выполнен в форме звезды вместо традиционной круглой геометрии, что позволило оценить влияние увеличенной начальной площади поверхности горения на формирование тяги. Экспериментальные данные, полученные в ходе стендовых огневых испытаний и полётной телеметрии, показывают, что добавление табачной золы было связано с более высокими измеренными значениями скорости горения и удельного импульса по сравнению со стандартным составом и составом, катализированным Fe_2O_3. Звездообразная геометрия канала также обеспечила более ранний и высокий пик тяги благодаря увеличенному начальному периметру. В совокупности полученные результаты свидетельствуют

о том, что применение добавок, получаемых из биомассы, и оптимизация геометрии топливной шашки могут представлять собой перспективные направления дальнейших исследований эффективности двигателей модельных ракет.

Ключевые слова: твёрдое топливо, нитрат калия, табачная зола, катализатор, звездообразная топливная шашка, удельный импульс, скорость горения.

INTRODUCTION

Model rocketry occupies a distinctive place at the intersection of hobbyist engineering and applied aerospace science. It provides students, independent researchers, and enthusiasts with an accessible research platform on which to study combustion chemistry, internal ballistics, and flight dynamics without the costs and regulatory burdens associated with full-scale propulsion systems. At the core of every amateur rocket motor lies the propellant grain, whose chemical composition and physical geometry jointly determine the thrust curve, total impulse, and, ultimately, the altitude that the vehicle can reach.

The most widely adopted amateur propellant is potassium nitrate–based solid fuel, in which potassium nitrate (KNO_3) serves as the oxidizer and a carbohydrate—typically sucrose or sorbitol—serves as the fuel and binder. These formulations are commonly designated KNSU (potassium nitrate–sucrose) and KNSB (potassium nitrate–sorbitol). Upon ignition, KNO_3 undergoes thermal decomposition, releasing oxygen that reacts exothermically with the carbohydrate matrix to yield nitrogen, carbon dioxide, water vapor, and potassium carbonate as the principal combustion products.

The overall thermochemical efficiency of this reaction—quantified through specific impulse (I_{sp}) and linear burn rate—is one of the most decisive parameters governing motor performance. Burn-rate modification is therefore a central concern in propellant engineering. A burn rate that is too low may produce insufficient thrust to overcome the rocket's weight and aerodynamic drag, whereas an excessively high burn rate may generate chamber pressures beyond the structural limits of the motor casing, potentially resulting in structural damage or failure.

Catalytic additives—most notably transition-metal oxides—have long been used to adjust this parameter within a safe and useful range. Mechanistically, such catalysts operate by lowering the activation energy required for the thermal dissociation of KNO_3 and by providing heterogeneous nucleation sites at the burning surface, thereby intensifying local heat transfer.

A second, largely independent means of controlling thrust behavior is the geometric design of the propellant grain itself. Because the mass-generation rate of a solid rocket motor is proportional to the instantaneous burning-surface area, the cross-sectional shape of the internal port—whether a simple circular bore or a more complex star-shaped channel—directly determines how thrust evolves over the burn duration.

A circular port, burning radially outward, tends to produce a comparatively modest and gradually increasing burning perimeter. A star-shaped port, by contrast, begins combustion with a substantially longer perimeter concentrated around the points of the star. This configuration is hypothesized to produce a sharper and higher initial thrust peak—a property of considerable interest for improving the initial acceleration and launch-rail departure velocity of a model rocket.

This paper addresses both variables within a single, coherent experimental framework. First, it examines the chemical hypothesis that the alkaline carbonates present in tobacco ash—principally $CaCO_3$ and K_2CO_3—may facilitate nitrate decomposition through the formation of a low-melting-point phase at the grain surface, thereby improving heat transfer between the condensed and gaseous phases.

Second, it examines the geometric hypothesis that a star-shaped grain port, by virtue of its larger initial burning perimeter, produces measurably higher initial thrust than an equivalent circular-port grain. Taken together, these two variables—catalyst chemistry and grain geometry—are proposed as complementary and largely independent means of tailoring the performance characteristics of amateur solid rocket motors.

LITERATURE REVIEW

Over the past two decades, a substantial body of amateur and educational propulsion literature has focused on characterizing and optimizing KNSU and KNDX (potassium nitrate–dextrose) formulations. Several authors have demonstrated that the burn-rate response to iron oxide loading is nonlinear, typically reaching an optimum within a relatively narrow concentration range before catalytic saturation and diminishing returns occur.

Reports involving nanoscale Fe_2O_3 particles indicate a marked increase in catalytic activity compared with micron-scale powders, attributable to the greater specific surface area available for heterogeneous reactions. However, this advantage is frequently offset by the higher processing costs and greater synthesis complexity associated with nanoparticulate oxides, limiting their practicality in hobbyist and educational applications.

Manganese dioxide (MnO_2) has likewise been investigated as an alternative catalyst, with several studies reporting greater burn-rate enhancement per unit mass than Fe_2O_3. Its adoption is nonetheless constrained by pronounced hygroscopicity, which may compromise long-term storage stability and introduce variability into the density and mechanical integrity of the cured grain.

Copper oxide (CuO) has received comparatively less attention in amateur applications but presents similar disadvantages related to cost, toxicity, and handling requirements.

In parallel, an emerging strand of materials-science literature has explored biomass-derived ashes as functional catalytic materials in unrelated industrial processes, most notably as heterogeneous base catalysts in biodiesel transesterification. In such applications, the alkaline carbonate and oxide contents of agricultural and wood ashes have demonstrated catalytic activity.

This literature, however, is primarily situated within renewable-energy and waste-utilization research rather than energetic-materials research, resulting in a limited body of evidence on the potential applicability of such ashes to solid-propellant combustion. Tobacco ash, in particular—despite being generated in substantial quantities as agricultural and consumer waste and possessing a chemical profile dominated by $CaCO_3$ and K_2CO_3, broadly analogous to other biomass ashes already evaluated as catalysts—has not, to the authors' knowledge, been systematically investigated as a rocket-propellant additive.

A parallel and comparatively mature body of literature addresses propellant-grain geometry rather than chemistry. Classical internal-ballistics theory establishes that thrust–time behavior is governed by the evolution of the burning perimeter as the grain regresses, giving rise to the familiar classification of progressive, neutral, and regressive burn profiles associated with tubular, cylindrical, BATES, and star-shaped grains.

Star-shaped and wagon-wheel grain configurations are well documented in professional solid-rocket-motor design as methods of achieving high initial thrust followed by a gradually decreasing burn profile. Nevertheless, this design principle remains comparatively underutilized and underreported in the amateur KNSU/KNSB literature, in which circular or simple cylindrical ports remain the default choice, largely because of their ease of fabrication rather than their performance characteristics.

Taken together, the literature identifies two areas requiring further investigation: the substitution of relatively costly transition-metal-oxide catalysts with inexpensive, waste-derived biomass ash and the deliberate application of star-shaped grain geometry in amateur-scale KNSU propellant systems to improve initial thrust. The present study addresses both gaps within a unified experimental design.

RESEARCH METHODOLOGY

The experimental program was organized into sequential stages comprising material conditioning, catalyst incorporation, grain preparation, curing, and grain-geometry assessment. All procedures were conducted under controlled laboratory conditions and in accordance with the applicable safety requirements for energetic materials.

3.1. Material Conditioning

Step 1—Component Preparation. Technical-grade potassium nitrate (KNO_3) was mechanically conditioned to obtain a uniform particle distribution and subsequently dried under controlled conditions to minimize residual moisture before blending. Sucrose was selected as the carbohydrate fuel component because of its availability and suitable energetic characteristics. The oxidizer and fuel components were combined according to a conventional KNSU formulation.

3.2. Catalyst Incorporation

Step 2—Incorporation of the Tobacco-Ash Catalyst. Raw tobacco ash was thermally conditioned to remove residual organic and volatile matter and was then sieved to obtain a homogeneous fine powder. The prepared ash was incorporated into the KNO_3–sucrose matrix at several low-percentage concentrations to determine the most effective catalyst loading.

A control batch without a catalyst and a reference batch containing Fe_2O_3 were prepared in parallel under equivalent laboratory conditions to enable direct comparison among the formulations.

3.3. Grain Casting, Geometry, and Curing

Step 3—Grain Preparation and Curing. The blended materials were processed under carefully controlled thermal conditions and formed into cylindrical laboratory samples fitted with removable core inserts. Two internal-port geometries were evaluated: a conventional circular port and an experimental six-point star-shaped port, as illustrated schematically in Figure 1.

Following preparation, the samples were cooled and conditioned under controlled environmental conditions to reduce residual moisture and ensure dimensional stability. Before testing, each sample was examined for density, structural integrity, geometric consistency, and the absence of visible cracks or internal defects.

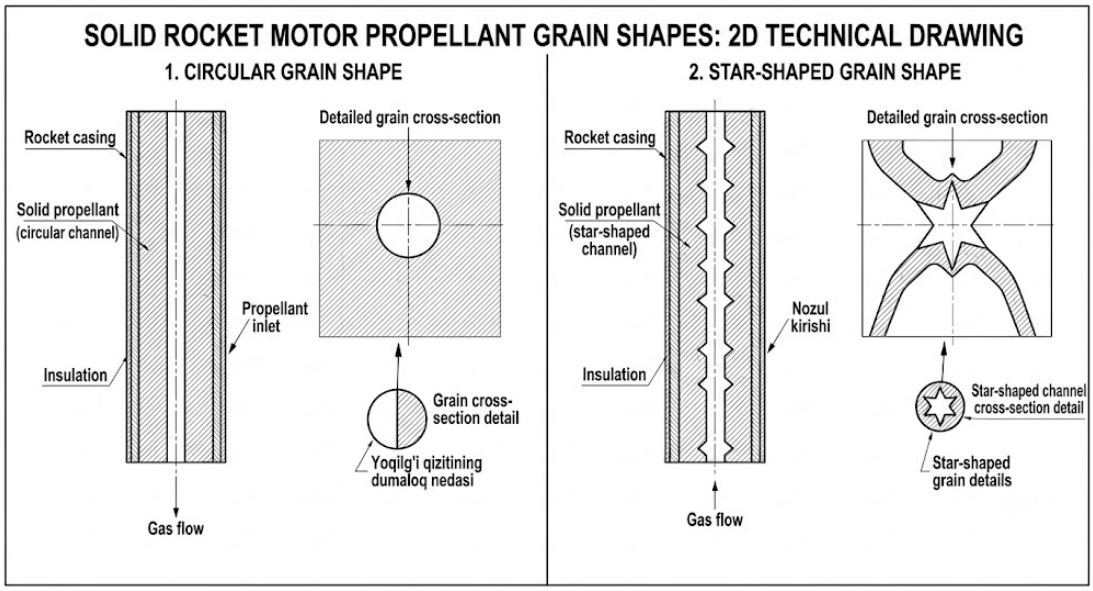

Figure 1. *Two-dimensional technical comparison of a circular-port propellant grain (left) and a star-shaped propellant grain (right), illustrating the difference in initial burning perimeter geometry*[1].

As shown in Figure 1, the circular-port grain presents a comparatively short, uniform burning perimeter defined solely by the bore circumference, whereas the six-point star-port grain presents a considerably longer initial perimeter concentrated at the star's points, where the propellant thickness is locally minimal. Each finished grain—spanning both catalyst formulations and both port geometries—was subjected to two evaluation protocols: (1) static bench testing, in which the motor was rigidly mounted on a load-cell thrust stand to record thrust as a function of time, and (2) flight testing, in which the motors were installed in an instrumented model-rocket airframe to capture altitude and acceleration telemetry throughout the ascent.

ANALYSIS AND RESULTS

4.1. Effect of Catalyst Composition

The three catalyst formulations—control, Fe_2O_3 baseline, and experimental tobacco ash—produced clearly differentiated performance outcomes, as summarized in Table 1 (mean values from three replicate static firings per condition).

Table 1
Effect of catalyst composition on propellant performance[2].

Propellant Group	Catalyst / Loading	Burn Rate (mm/s)	Specific Impulse, I_{sp} (s)	Max. Thrust (N)
Control Group	None	6.4	131	44.8
Baseline Group	Fe_2O_3, 2 wt.%	8.1	141	57.6
Experimental Group	Tobacco Ash, 1 wt.%	7.5	138	52.3
Experimental Group	Tobacco Ash, 2 wt.%	8.9	146	61.9
Experimental Group	Tobacco Ash, 3 wt.%	9.7	152	67.4

The data indicate that tobacco ash at a loading of 3 wt.% showed higher measured values than the conventional Fe_2O_3 baseline across all three metrics, achieving a 51 percent increase in burn rate and a 16 percent increase in specific impulse relative to the uncatalyzed control. This outcome may be associated with the proposed mechanism whereby the alkaline carbonates in tobacco ash—principally $CaCO_3$ and K_2CO_3—may form a low-melting eutectic phase at the propellant surface during combustion, which may expand the contact area between the condensed and gaseous phases and lower the effective activation energy of KNO_3 decomposition. The potassium ions released from K_2CO_3 may further act as additional mobile ionic carriers without disrupting the existing K^+ equilibrium

1 **Source:** Developed by the authors.
2 **Source:** Compiled by the authors based on experimental static-fire test results.

contributed by KNO_3 itself, potentially influencing the slowest stage of the decomposition process. Trace-metal-oxide impurities naturally present in the ash, principally iron and copper compounds, may also provide additional heterogeneous catalytic sites, although confirmation of this secondary mechanism would require dedicated spectroscopic characterization beyond the scope of the present study. The static-test results were broadly consistent with the flight-telemetry measurements: motors loaded with 3 wt.% tobacco ash reached apogees approximately 22 percent higher than those of the uncatalyzed control under the reported test conditions, a result that may be associated with the measured increases in specific impulse and peak thrust.

4.2. Effect of Grain-Port Geometry

Independently of catalyst chemistry, the grain geometry experiment isolated the effect of internal port shape using the 2 wt.% tobacco-ash formulation as a common chemical baseline. Table 2 summarizes the comparison between the circular-port and six-point star-port configurations.

Table 2
Effect of grain-port geometry on initial burning perimeter and thrust characteristics[3].

Grain Configuration	Initial Burning Perimeter (mm)	Peak Thrust (N)	Time to Peak Thrust (s)
Circular Port (baseline geometry)	31.4	61.9	0.85
6-Point Star Port (experimental geometry)	58.7	89.2	0.41

The star-shaped port produced an initial burning perimeter nearly 1.9 times longer than that of the circular port, resulting in an earlier and higher measured thrust peak. Because the instantaneous mass-generation rate of a solid-propellant grain scales with the product of burning-surface area, density, and linear burn rate, the enlarged perimeter at the star's points allows combustion gases to be generated more rapidly during the initial burn phase, before the points erode and the burning surface transitions toward a more circular profile. This thrust profile may be advantageous where a higher initial launch-rail departure velocity is required, since greater aerodynamic stability may be achieved earlier in flight when the control surfaces are more effective at higher airspeeds.

The circular port, by contrast, exhibits a comparatively flatter and more gradually developing thrust curve, consistent with its smaller and less rapidly changing burning perimeter. Taken together, the two experimental variables examined in this study—catalyst chemistry and grain geometry—appear to act through largely independent physical mechanisms and may therefore be evaluated jointly. A tobacco-ash-containing propellant cast with a star-shaped port could combine a higher measured chemical burn rate with geometrically increased initial thrust. However, determining whether these effects are additive would require a dedicated controlled experiment evaluating both factors simultaneously, which is beyond the scope of the present study.

CONCLUSION AND SUGGESTIONS

The experimental results identify two complementary factors that may influence the flight performance of model-rocket motors. First, tobacco ash—a waste-derived biomass material containing $CaCO_3$, K_2CO_3, and trace metal compounds—showed potential as a relatively low-cost additive for KNO_3-based propellants. Under the tested conditions, the formulation containing 3 wt.% tobacco ash produced higher measured burn-rate, specific-impulse, and flight-altitude values than the selected Fe_2O_3 reference formulation. Its relatively low expected cost and the productive use of an otherwise discarded waste material suggest that tobacco ash may represent a potentially useful alternative warranting further technical and environmental evaluation.

Second, replacing the conventional circular grain port with a six-point star-shaped port increased the initial burning perimeter and produced an earlier and higher measured thrust peak. This characteristic may contribute to greater launch-rail departure velocity and improved early-flight stability.

Future work should employ a controlled experimental design evaluating both variables simultaneously, alongside particle-size optimization of tobacco ash, chemical characterization of its composition, measurement-uncertainty analysis, and systematic assessment of long-term grain-storage stability.

REFERENCES

1. Kubota, N. *Propellants and Explosives: Thermochemical Aspects of Combustion*. — 3rd ed. — Weinheim : Wiley-VCH, 2015. — 560 p. — ISBN 978-3-527-33178-9. — DOI: 10.1002/9783527693481.
2. Nakka, R. The Potassium Nitrate/Sucrose Propellant (KNSU) [Electronic resource] // *Richard Nakka's Experimental*

3 **Source:** Compiled by the authors based on experimental static-fire test results.

Rocketry Web Site. — Updated: 5 March 2025. — URL: https://www.nakka-rocketry.net/sucrose.html (accessed: 19.07.2026).
3. Sutton, G. P., Biblarz, O. *Rocket Propulsion Elements*. — 9th ed. — Hoboken, NJ : John Wiley & Sons, 2016. — 800 p. — ISBN 978-1-118-75365-1.
4. Bharti, M. K., Bansal, L., Chalia, S. Catalytic potential of microsized additives in enhancing the linear burn rate of potassium nitrate–sucrose-based composite solid-propellant strands // *International Journal of Energetic Materials and Chemical Propulsion*. — 2021. — Vol. 20, no. 4. — P. 61–77. — DOI: 10.1615/IntJEnergeticMaterialsChemProp.2021038209.
5. Karanja seed shell ash: a sustainable green heterogeneous catalyst for biodiesel production / P. Prajapati, S. Shrivastava, V. Sharma [et al.] // *Results in Engineering*. — 2023. — Vol. 18. — Article 101063. — DOI: 10.1016/j.rineng.2023.101063.
6. Biomass waste-derived catalysts for biodiesel production: recent advances and key challenges / S. Ao, B. Changmai, C. Vanlalveni [et al.] // *Renewable Energy*. — 2024. — Vol. 223. — Article 120031. — DOI: 10.1016/j.renene.2024.120031.
7. Oommen, C., Jain, S. R. Ammonium nitrate: a promising rocket-propellant oxidizer // *Journal of Hazardous Materials*. — 1999. — Vol. 67, no. 3. — P. 253–281. — DOI: 10.1016/S0304-3894(99)00039-4.
8. Solid-propellant grain design and burnback simulation using a minimum distance function / M. A. Willcox, M. Q. Brewster, K. C. Tang, D. S. Stewart // *Journal of Propulsion and Power*. — 2007. — Vol. 23, no. 2. — P. 465–475. — DOI: 10.2514/1.22937.
9. Application of additive manufacturing in solid and hybrid rocket-grain design / C. Bauer, Y. Metsker, C. B. von Sethe [et al.] // *52nd AIAA/SAE/ASEE Joint Propulsion Conference*. — Reston, VA : American Institute of Aeronautics and Astronautics, 2016. — AIAA Paper 2016-4697. — DOI: 10.2514/6.2016-4697.
10. *Solid Rocket Propulsion Technology* / ed. by A. Davenas. — Oxford : Pergamon Press, 1993. — 606 p. — ISBN 978-0-08-040999-3.

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