Unlocking the potential of computational fluid dynamics in Nigerian polymer research: current trends and future directions

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Recent advancements in polymer research have focused on key challenges such as polymeric waste management, material degradation, property enhancement, and development of novel applications. Globally, researchers increasingly leverage both experimental and computational techniques to address these issues. However, in Nigeria, the application of computational methodologies—particularly Computational Fluid Dynamics (CFD)—remains significantly underutilized. This study underscores the transformative potential of CFD as a strategic tool for advancing polymer research in Nigeria. Through a comprehensive review of relevant literature, the current status of CFD adoption in polymer studies is examined, and prospective opportunities for its integration are identified. By articulating the benefits and implementation prospects of CFD within the Nigerian research context, this report aims to encourage its broader adoption, thereby fostering innovation, improving cost-efficiency, and driving the future direction of polymer science in the country.

Keywords: CFD, polymer; material design; modeling, computational approach, Nigeria.

INTRODUCTION

Secondary processing of polymers into functional products typically involves a melting phase facilitated through extrusion, injection molding, blow molding, transfer molding, and other techniques. In each of these processes, the polymer must be converted into a flowable state before being shaped into the desired article. Consequently, various process parameters—such as temperature, flow rate, and pressure—directly influence both the quality of the final product and the total processing time. For instance, in pelletization, the quality of polymer pellets is primarily governed by processing time, where shorter durations tend to stabilize product quality and boost production rate [1].

Importantly, the rheological and thermal behavior of polymers varies across different materials, necessitating precise and material-specific designs during extrusion and similar processes. The ability to predict and control polymer flow behavior is vital for ensuring seamless production and product consistency. In this context, Computational Fluid Dynamics (CFD) has emerged as an indispensable tool. CFD enables the mathematical modeling and numerical simulation of fluid flow phenomena, offering insights that aid in optimizing die design, reducing material waste, cutting down production time, and improving overall processing efficiency [1–3].

While CFD has become a well-established tool in polymer industries and academic research across many developed countries, its integration into polymer research and industrial applications in developing nations—such as Nigeria—remains significantly underexplored and poorly documented. Existing literature and industry surveys [4–14] indicate a scarcity of empirical data and a lack of systematic reviews that assess adoption trends, practical applications, or policy support for CFD within Nigeria's polymer sector. Most existing studies primarily adopt experimental approaches, focusing on the synthesis of polymers or polymer-based materials from monomers or waste sources, as well as on performance evaluation and optimization. However, these studies often pay minimal attention to the potential applications of CFD, revealing a substantial gap in both knowledge and practice regarding its use in polymer science research in Nigeria. Addressing this gap is crucial, especially as Nigeria aspires to expand its local polymer production, improve material efficiency, and adopt modern processing technologies. The growing complexity of polymer processing in both academic and industrial contexts demands evidence-based decision-making, for which CFD can play a transformative role.

This paper, therefore, aims to critically assess the current trends, extent of adoption, and future prospects of CFD applications in Nigeria's polymer research landscape. It highlights the benefits of CFD integration, showcases successful case studies from advanced economies, and proposes strategic

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directions to foster greater adoption within Nigeria. By doing so, the paper underscores the urgent need to embrace computational modeling as a key enabler of innovation and competitiveness in the Nigerian polymer industry.

METHOD EMPLOYED IN THIS LITERATURE SURVEY

This study employed a two-pronged approach to assess the extent of Computational Fluid Dynamics (CFD) adoption in Nigerian polymer research. First, existing literature was reviewed to demonstrate the potentials of CFD and how it has been successfully utilized in global studies for product design, process optimization, and reduction of physical prototyping. These international reports provided the basis for highlighting the benefits CFD can offer in enhancing the quality and efficiency of polymer-related research and development.

The second aspect of the survey focused specifically on research carried out in Nigeria. A comprehensive review was conducted on selected Nigeria-based peer-reviewed journals that regularly publish studies in materials and polymer science. The journals examined include the Journal of the Nigerian Society of Physical Sciences (JNSPS), the Journal of the Chemical Society of Nigeria (JCSN), the Journal of the Nigerian Society of Chemical Engineers (JNSCHE), and the Nigerian Journal of Materials Science and Engineering (NJMSE). These journals were chosen due to their reputability and consistent publication of polymer-related research within the Nigerian academic context.

All articles published in these journals, from their maiden issues up to the year 2025, were manually reviewed volume-by-volume and issue-by-issue through their online databases. This manual screening process was carried out without the use of keywords to ensure a thorough identification of all relevant studies focused on polymers or polymer-based materials. Articles that involved polymer synthesis, property optimization, kinetic modeling, or polymer-related waste management were included. However, studies employing CFD outside the scope of polymer applications, such as those focused solely on fluid dynamics in unrelated fields, were excluded.

The survey methodology and scope are illustrated diagrammatically in Figure 1. Figure 1a presents a graphical overview of the research focus, specifically highlighting the core areas of polymer research explored in relation to CFD usage. Figure 1b outlines the schematic flow of the survey approach, indicating the journals analyzed, the screening procedure adopted, and the comparative trend analysis carried out between conventional polymer research themes and the incorporation of CFD in those studies.

The purpose of this methodology was to provide a data-driven understanding of how CFD has been utilized—or overlooked—in Nigeria’s polymer research landscape. It aims to quantify the level of attention given to computational modeling approaches in local publications and to identify potential gaps in adoption when compared with global trends. This forms the basis for highlighting the need for increased awareness and application of CFD in future Nigerian polymer science research.

CFD IN POLYMER RESEARCH: CURRENT PERSPECTIVES AND NIGERIAN CONTEXT

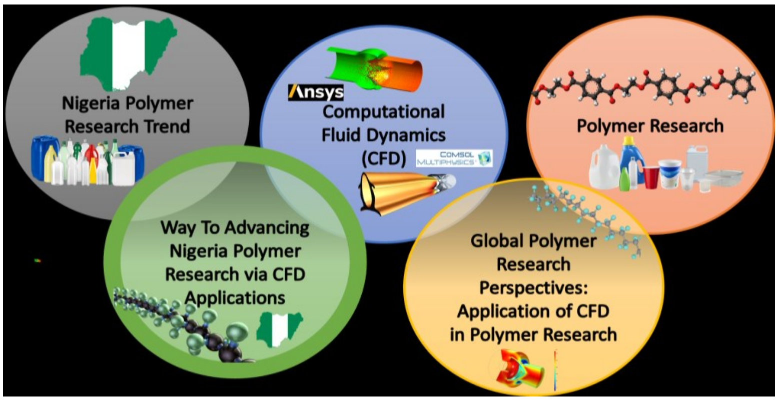
SimScale [15] described computational fluid dynamics (CFD) referring to a method of mathematically modeling a physical phenomenon that involves the flow of fluids inside a processing system unit and the solution of models that have been constructed numerically using computational tools. CFD is an approach to modeling a physical phenomenon. These computational tools have made the approach much easier with the advances reported in ICT and the introduction of different graphic user interfaces (GUI), making it more user-friendly to researchers. The significance of the CFD approach to a process scale-up cannot be overemphasized in terms of design, efficient management of mass, momentum, and energy transport involved in a production process [2, 3]. Technopedia [16] further indicated that the CFD approach goes a long way to give insight into patterns or forms of flow, which would be difficult, expensive, or impossible to study using traditional techniques.

Applications of CFD in polymer design and analysis

The utilization of the computational fluid dynamic study approach in the design and analysis of high-performing new polymers has been demonstrated mainly in the literature, where it has been adopted in ascertaining the potential of a designed objective or goal [17]. A schematic block flow depicting the processes involved in the deployment of CFD is presented in Figure 2, as obtained from the literature [18].

Many works have employed the computational fluid dynamic modeling approach in polymer processing studies. Some of the works investigated the behavior of materials in a reactor during the processing, including how some reactor operating parameters influenced the product's properties in terms of quality, conversion, and homogeneity.

Other studies employed the use of the approach to understanding the phenomena behind the experimental observations from a laboratory study, like understanding what promotes polymer adhesion in a polymerizer, that is, polymerization reactor, which could be batch, CSTR, fluidized bed, and any other reactor model [18–20].



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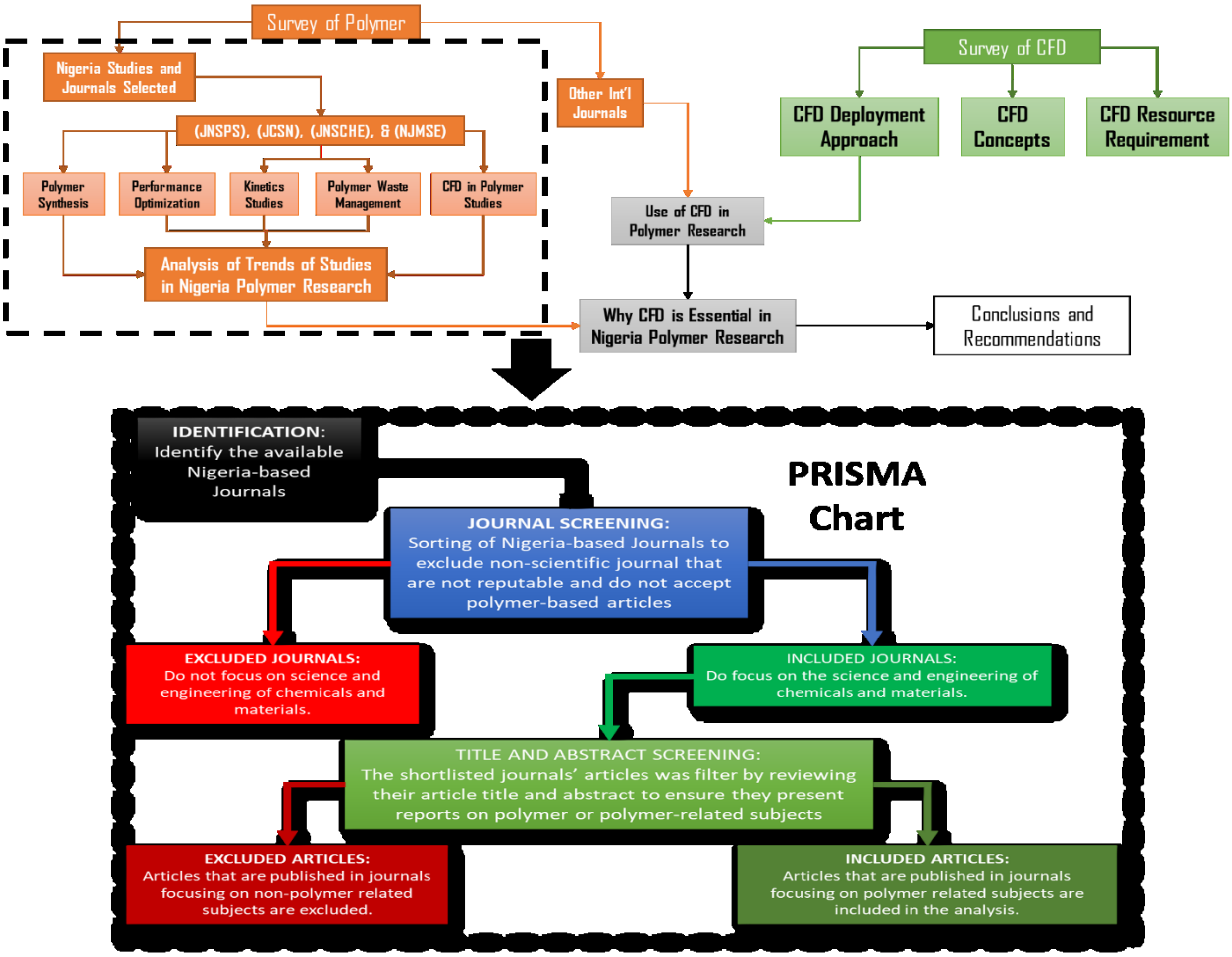


(b)

Figure 1. (a) Overview graphical illustration of the key components in the survey, and (b) Schematic approach deployed for the literature survey with the PRISMA chart for this report.

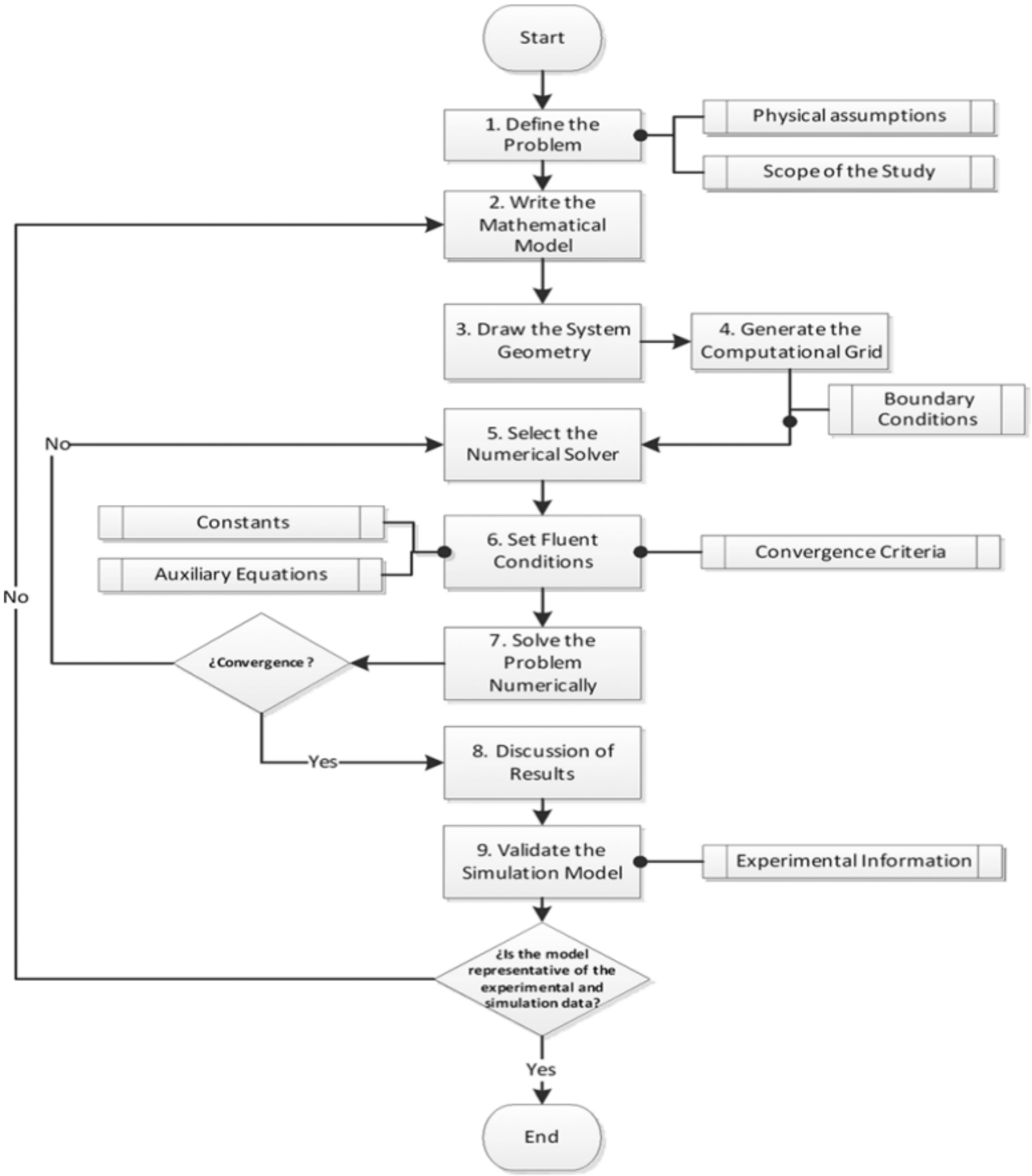


Figure 2. The block flow of serial steps involved in the deployment of CFD *via* the use of FLUENT simulation application package [18].

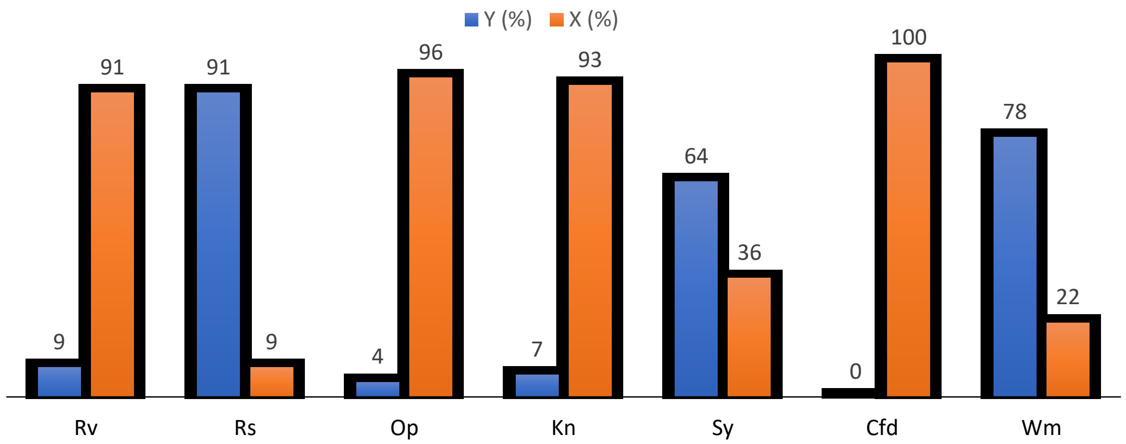


Figure 3. Distribution of research studies on polymer-based materials in Nigeria, obtained from the literature survey (Note: Rv = reviews, Rs = experimental research, Op = optimization, Kn = kinetic and thermodynamic studies, Sy = synthesis, CFD application, Wm = waste management and environments).

Some works deploy this approach to study the interaction of the polymer with selected materials of interest. Similar to studies that tend to investigate the interactions of selected polymers with oil droplets to see if the oil droplet deforms and how the elastic property of the polymer influences the deformation processes during the simulation of enhanced oil recovery (EOR) [21, 22]. The CFD approach is typically deployed in the independent study of each processing unit available singly in the processing of polymer's production networks, unlike those cases of the process modeling approach, which can evaluate the entire networks.

Current trends in polymer research in Nigeria

The extent of the application of CFD in polymer research by Nigerian experts, particularly in the design and analysis of secondary polymer processing technologies, is presented in Figure 3 and Table 1. Findings from the literature survey reveal that a significant portion of the reported research focuses on polymer synthesis, which accounts for approximately 64% of the total studies on Figure 3 identified across selected peer-reviewed Nigerian journals.

Other areas of research include kinetic modeling and optimization studies, which contribute 4% and 7% of the reported works, respectively. However, the application of CFD in polymer-based research remains strikingly absent. The data collected from the reviewed journals show that 0% of the studies utilized CFD, indicating a complete lack of attention to this valuable computational tool in the surveyed literature.

Table 1 summarizes the various works published in four reputable Nigeria-based journals: Journal of the Nigerian Society of Physical Sciences (JNSPS), Journal of the Chemical Society of Nigeria (JCSN), Nigerian Journal of Materials Science and Engineering (NJMSE), and Journal of the Nigerian Society of Chemical Engineers (JNSChE). Each entry details whether the study involved reviews (Rv), experimental research (Rs), optimization (Op), kinetic and thermodynamic studies (Kn), synthesis (Sy), CFD application, or waste management and environmental analysis (Wm).

A total of 78% (in Figure 3) of the analyzed studies addressed aspects of polymer waste management and environmental impact. These included investigations into polymer waste recycling [56], biodegradability of polymer [49, 52], synthesis of polymer composites using agro-wastes such as orange and plantain peels [54], sugarcane bagasse [52], palm kernel shell [50], banana stem [38], and other agro-wastes [39–41].

Despite this promising focus on sustainability (in Figure 3), the absence of CFD deployment across all reviewed studies is a significant gap. Notably, previous reviews have also failed to examine or highlight ++the potential or actual use of CFD in Nigerian polymer research. This lack of integration may be attributed to several factors, including limited research funding, shortage of expertise in CFD applications, and insufficient infrastructure or access to commercial CFD software and high-performance computing facilities.

In summary, while Nigerian polymer research demonstrates strength in synthesis and environmental sustainability, it falls short in adopting advanced computational tools like CFD as shown in Figure 3 and Table 1. Addressing this gap is critical for advancing process optimization, improving material properties, and reducing time and cost associated with experimental design. The promotion of CFD integration in polymer research would require deliberate investment in capacity building, infrastructure development, and academic-industry collaboration.

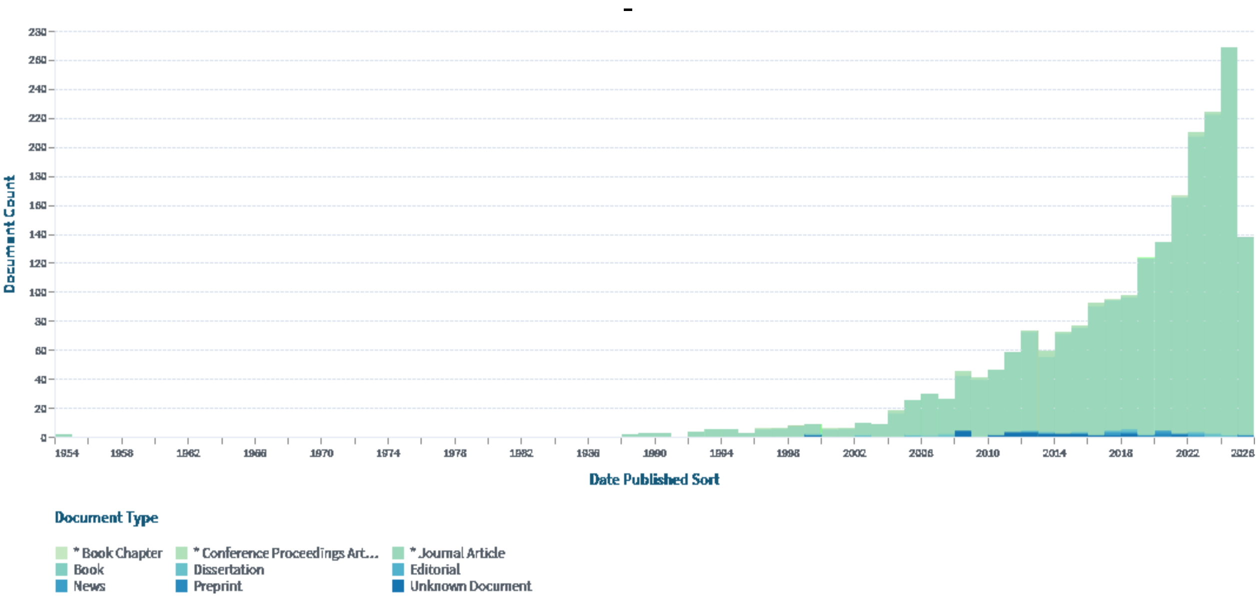
Trend of CFD deployment in polymer researches across the globe

A bibliometric analysis was conducted using the keywords "CFD" or "Computational Fluid Dynamics" and "polymer", with the aid of Lens online platform (https://www.lens.org/lens/search/scholar/analysis?q=CFD%20or%20Computational%20fluid%20dnamic%20AND%20polymer). The global trend in CFD-related polymer research has shown continued growth, as evident in Figure 4a which illustrates annual publication counts.

Table 1. Works reported by Nigerian polymer experts (Note: Y=Yes, N=No, Mgt=Management)

Journal (References)	Reported study on the selected peer-reviewed material-based Journal (Available in the journal online database)	Review (Rv)	Research (Rs)	Optimization (Op)	Kinetics & Thermo (Kn)	Synthesis (Sy)	CFD	Waste Mgt & Environment (Wm)
JNSPS [6,14]	A review on Transforming plastic wastes into fuel	Y	N	N	N	N	N	Y
JNSPS [6,23]	Degradation of PET nanoplastic oligomers at the novel phl7 target:insights from molecular docking and machine learning	N	Y	Y	N	Y	N	N
JNSPS+ [6,24]	Enhancing cellulose fiber properties from chromolaena odorata and anana comosus through novel pulping chemical mixtures	N	Y	N	N	Y	N	N
JNSPS [6,25]	Polychlorinated biphenyls (PCBs) in sediments and fish from dredged tributaries and creeks of river Ethiope, South-South, Nigeria: sources, risk assessment and bioaccumulation	N	Y	N	N	N	N	Y
JNSPS [6,26]	Sustainable remediation of vancomycin polluted water using pyrolysis biochar of pressed oil palm fruit fibre	N	Y	N	N	Y	N	Y
JCSN [7,27]	Studies on the thermodynamic properties of natural rubber composites filled with clay and corn cob	N	Y	N	N	Y	N	Y
JCSN [7,28]	Development and evaluation of natural rubber membranes for sustained transdermal drug release applications	N	Y	N	N	Y	N	N
JCSN [7,29]	Tsolation and characterization of cellulose from pentaclethra macrophylla benth pod biomass wastes for polymer reinforcement composite	N	Y	N	N	Y	N	Y
JCSN [7,30]	Study of using natural fillers on the biodegradation properties of virgin/waste low density polyethylene and virgin/waste high density polyethylene composites.	N	Y	N	N	Y	N	Y
JCSN [7,13]	Comparative study of the effect of poly(lactic- acid), starch, charcoal on physico-mechanical properties of virgin and waste low density polyethylene composites	N	Y	N	N	Y	N	Y
JCSN[7,31]	Spatial assessment and pollution analysis of packaged sachet water sold in selected local government areas of kano state, Nigeria	N	Y	N	N	N	N	Y
JCSN [7,12]	Polycyclic aromatic hydrocarbons (pahs) in the fruits of cucumis sativus from two markets within aba metropolis	N	Y	N	N	N	N	Y
JCSN [7,32]	Effect of dye sulphonation on the dyeing of nylon, 6, 6 with 1-hydroxy-2-phenylazo-6-[2-chloro-4-[phenylamino] triazin-6- ylamino] naphthalene- 3-sulphonic acid reactive dye	N	Y	N	N	N	N	Y
JCSN [7,33]	Development and evaluation of natural rubber membranes for sustained transdermal drug release applications	N	Y	N	N	Y	N	Y
J++CSN [7,31]	Spatial assessment and pollution analysis of packaged sachet water sold in selected local government areas of kano state, Nigeria	N	Y	N	N	N	N	Y
JCSN [7,12]	Polycyclic aromatic hydrocarbons (pahs) in the fruits of cucumis sativus from two markets within aba metropolis	N	Y	N	N	N	N	Y
JCSN [7,10]	Analysis of bottled drinking water sold in awka metropolis, anambra state, Nigeria	N	Y	N	N	N	N	Y
JCSN [7,11]	Molecular modeling analysis of per- and polyfluoroalkyl substances binding on human fertilization proteins - izumo1 and egg surface juno	N	Y	N	N	N	N	Y
JCSN [7,34]	Contamination of pet bottled carbonated soft drinks sold in nigeria after long storage due to antimony leaching: risk assessment	N	Y	N	N	N	N	Y
JCSN [7,35]	Isolation and characterization of cellulose from pentaclethra macrophylla benth pod biomass wastes for polymer reinforcement composite	N	Y	N	N	Y	N	Y
JCSN [6,36]	Use of natural cross linkers in molecularly imprinted polymer technology - past, present and future	Y	N	N	N	Y	N	N
JCSN [7,37]	Chitosan-starch polymeric blend hydrogels as scavengers of antibiotics from simulated effluent: sorbent characterization and sorption kinetic studies	N	Y	N	Y	Y	N	N

JCSN [7,38]	Properties of natural rubber compounded with modified banana pseudostem fibres and calcium carbonate	N	Y	N	N	Y	N	Y
JCSN [7,39]	Surface morphlogy characterization on green adhesive prepared using agricultural and plastic waste material as composites	N	Y	N	N	Y	N	Y
JCSN [7,40]	Graft copolymerization of dextrin onto concentrated natural rubber for the production of baby feeder teat.	N	Y	N	N	Y	N	N
JCSN [7,41]	Studies on the thermodynamic properties of natural rubber composites filled with clay and corn cob	N	Y	N	Y	Y	N	N
J+CSN [7,42]	Development and evaluation of natural rubber membranes for sustained transdermal drug release applications	N	Y	N	N	Y	N	N
JCSN [7,43]	Spatio-temporal occurrence, sources, and human health risk of 16-polycyclic aromatic hydrocarbons in anthropogenic vectored soils	N	Y	N	N	N	N	Y
+JCSN [7,44]	Proximate analysis and determination of polycyclic aromatic hydrocarbons in processed animal skin sold in major markets in south west nigeria	N	Y	N	N	N	N	Y
JCSN [7,45]	Study of using natural fillers on the biodegradation properties of virgin/waste low density polyethylene and virgin/waste high density polyethylene composites	N	Y	N	Y	Y	N	Y
JCSN [7,46]	Comparative study of the effect of poly(lactic- acid), starch, charcoal on physico-mechanical properties of virgin and waste low density polyethylene composites	N	Y	N	N	Y	N	Y
JCSN [7,47]	Polycyclic aromatic hydrocarbons (pahs) in the fruits of cucumis sativus from two markets within aba metropolis	N	Y	N	N	N	N	Y
JCSN [7,48]	Polycyclic aromatic hydrocarbon in sediment, ground and surface water resources in coastal areas of ondo state, nigeria	N	Y	N	N	N	N	Y
NJMSE [4,49]	Processing, degradation and applications of synthetic biodegradable polymers: a review	Y	N	N	N	Y	N	Y
NJMSE [4,50]	Fabrication of palm kernel shell epoxy composites and study of their mechanical properties	N	Y	N	N	Y	N	Y
NJMSE [5,51]	Production of uniformly disperse carbon nanotube/high density polyethylene nanocomposite using novel nanofeeder injection moulding machine	N	Y	N	N	Y	N	N
NJMSE [5,52]	Preparation and assessment of biodegradable polyurethane foams from sugar bagasse	N	Y	N	N	Y	N	Y
NJMSE [5,53]	Thermal and mechanical properties of high-density polyethylene (hdpe)/leather composite	N	Y	N	N	Y	N	N
NJMSE [5,51]	Properties of chemically modified baobab pod/sisal fiber reinforced low-density polyethylene hybrid composite	N	Y	N	N	Y	N	Y
JNSChE [4,54]	Optimization of microwave pretreatment conditions of orange and plantain peels for polygalacturonase production by aspergillus awamori cicc 2040	N	Y	Y	N	Y	N	Y
JNSChE [4,55]	Effect of temperature and catalyst modification on thermocatalytic degradation of low-density polyethylene	N	Y	N	N	Y	N	Y
JNSChE [4,56]	Recycling of rigid polyurethane waste –a cost reduction strategy in rigid polyurethane foam production	Y	N	N	N	Y	N	Y
JNSChE [4,9]	Air emissions from stepwise co-pyrolysis of plastic mixtures	N	Y	N	N	N	N	Y
JNSChE [4,8]	Flow and compaction properties of excipients developed from biopolymer waste snail shell and influencing factors	N	Y	N	N	Y	N	Y
JNSChE [4,57]	Air emissions from stepwise co-pyrolysis of plastic mixtures	N	Y	N	N	N	N	Y
Summary	Descriptions	Rv	Rs	Op	Kn	Sy	Cfd	Wm
	Frequency of works with Y	4	41	2	3	29	0	35
	Frequency of works with N	41	4	43	42	16	45	10



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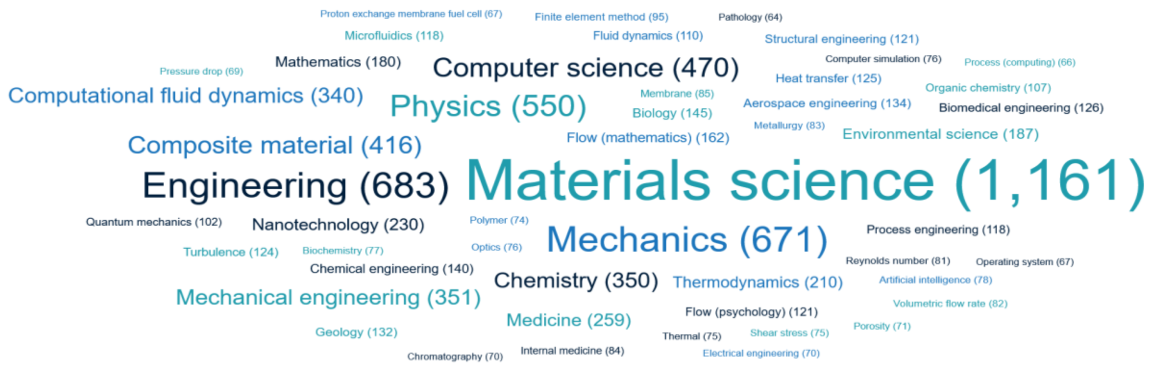

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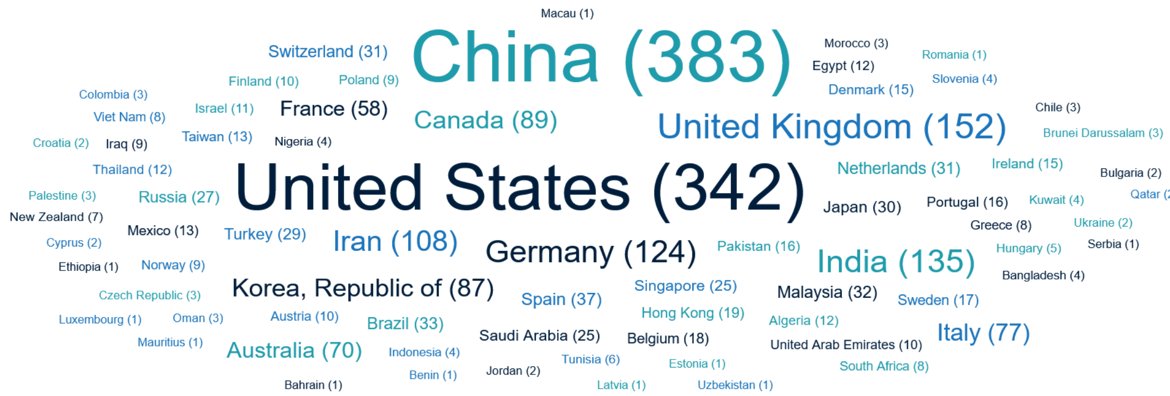

(c)

Figure 4. (a) Scholarly works over time, (b) Top fields of study in such research, and (c) Most active countries involved in the deployment of CFD in their polymer science research (Source: https://www.lens.org/lens/search/scholar/analysis?q=CFD%20or%20Computational%20fluid%20dynamic%20AND%20polymer)

Further insights from the analysis (see Figure 4b) show that fields such as materials science, engineering mechanics, and physics dominate the research in polymer science employing CFD. The analysis of active countries and regions (see Figure 4c) highlights China, the United States, the United Kingdom, India, Germany, and Iran as leading contributors. In contrast, Nigeria and other developing nations—including Benin, Bangladesh, Romania, and Kuwait—remain less active in CFD-focused polymer research. This emphasizes the need for increased engagement and capacity development in these regions to leverage CFD's potential in advancing polymer science.

Potential impact of CFD on Nigeria's polymer research landscape.

Integrating CFD into polymer research offers significant advantages, particularly for Nigeria's scientific and industrial communities. CFD has the potential to reduce the cost and time associated with experimental trial-and-error by providing detailed insight into the impact of various constraints under controlled virtual environments. This makes it a powerful tool for enhancing process understanding, optimizing operating conditions, and facilitating efficient process scale-up in polymer production.

One major area where CFD adds value is in analyzing the effect of non-homogeneity and short-circuiting in polymerization reactors. For instance, Patel *et al.* [58] used CFD to study how impeller speed and residence time affect the flow pattern and conversion of styrene during polymerization. Their results showed how unreacted monomer distribution could be better managed to improve reactor performance. Similarly, Xie *et al.* [59] applied CFD to gain insights into anionic polymerization behavior in tubular reactors, further demonstrating its versatility.

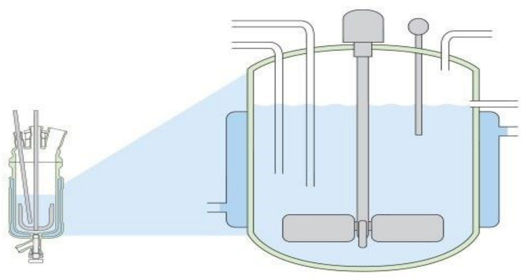

Figure 5. Process scale illustration for a chemical reactor [60].

CFD also plays a crucial role in process scale-up, offering the ability to simulate complex interactions of mass, heat, and momentum transfer that typically occur in large-scale reactors. By capturing these dynamics, researchers can translate laboratory findings presented in Figure 5 to industrial scales more reliably, ensuring better conversion efficiency and process performance.

Temperature distribution within reactors is another critical factor in polymer production. Jongpaijit & Bumroongsri [61] utilized CFD to study the polymerization of propylene into polypropylene. Their work, shown in Figure 6, revealed that increasing monomer velocity led to a steadier temperature distribution within the reactor bed, improving process stability and product consistency.

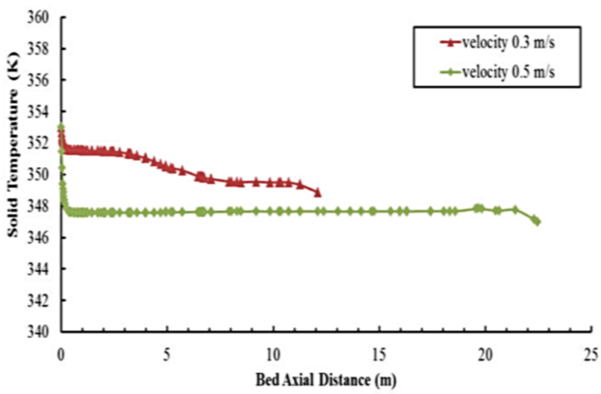

Figure 6. Effect of change in monomer velocity on polymerizer (reactor) temperature distribution in a propylene polymerization study performed with the use of CFD tool [61].

Furthermore, CFD can aid in the investigation of polymer rheology. Pineda-Torres *et al*. [18] modeled the influence of stirrer speed and time on the viscosity of a copolymer product. Their simulations provided a clearer understanding of how changes in operating parameters affect viscosity and other rheological properties. Figure 7 presents the block flow employed during the deployment of CFD in the polymer rheological studies.

Overall, deploying CFD tools in Nigeria's polymer research landscape can significantly enhance the quality and efficiency of research outcomes. By leveraging its capabilities, researchers can reduce dependence on costly experiments, improve process control, and contribute meaningfully to the country's technological advancement in polymer science.

Infrastructure and capacity needs for CFD implementation

The implementation of the CFD study approach in future polymer design research in Nigeria requires a range of essential resources to ensure effective and sustainable deployment. Chief among these is the access to high-performance computing (HPC) infrastructure, which may include institutional computing clusters, subscriptions to supercomputers, or cloud-based computing services (see Figure 8). These computational resources are critical for running the complex simulations involved in CFD studies.

In addition to hardware infrastructure, access to advanced software is vital. CFD simulation tools presented in Figure 9 like ANSYS Fluent, COMSOL Multiphysics, OpenFOAM, SimScale, SU2 Code, and Elmer are examples of platforms commonly used in computational modeling.

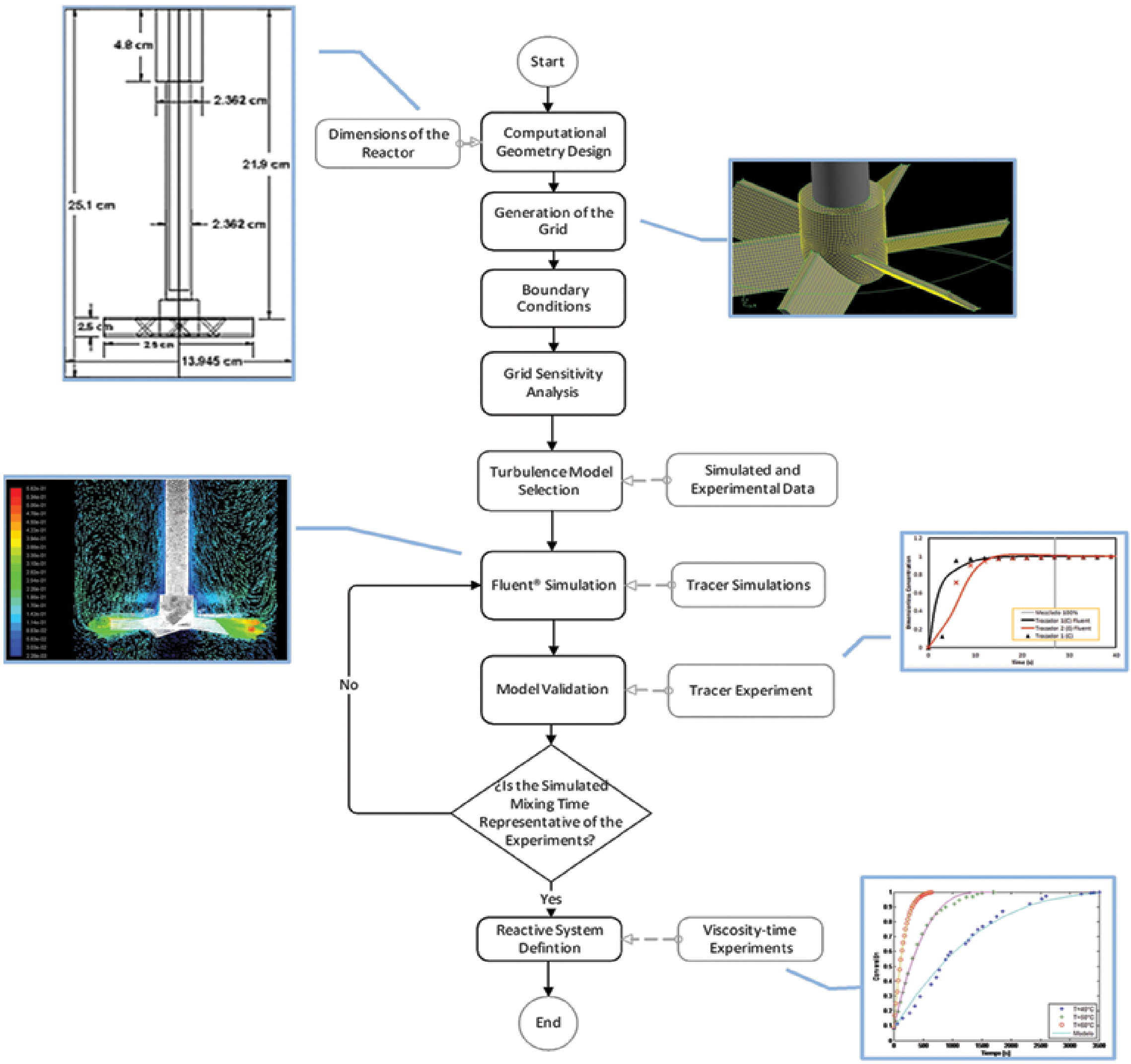

Figure 7. Method deployed by Pineda-Torres *et al.* [18] in their simulation in FLUENT.

Figure 8. Possible computing devices for the running of the simulation jobs.

Figure 9. Series of CFD software alternatives applicable for the modeling and simulation of the polymer science study.

Some of these tools require pre-processing and geometry development using computer-aided design (CAD) software such as AutoCAD. These software applications collectively form the digital ecosystem necessary for comprehensive CFD analysis, from geometry creation to meshing, simulation, and result interpretation [62–64].

Strategic directions and policy recommendations

To harness the full potential of CFD in Nigeria's polymer research and innovation landscape, deliberate policy actions and strategic investments are essential. First, universities and research institutions should integrate CFD modeling into polymer science and chemical engineering curricula to build foundational expertise among emerging scientists and engineers. Complementing this, targeted training workshops and research internships especially through collaborations with international institutions experienced in CFD will accelerate local competence development.

Simultaneously, national and institutional research funding agencies should prioritize computational modeling within their grant portfolios. Providing access to licensed CFD software and high-performance computing (HPC) facilities will empower researchers to perform more accurate and efficient simulations. Interdisciplinary projects that combine CFD with experimental polymerization studies should also be encouraged, as such collaborations ensure result validation, strengthen theory–practice integration, and enhance real-world applicability.

Strategic partnerships among academia, industry, and government agencies must be fostered to promote knowledge transfer and facilitate the commercialization of CFD-optimized polymer processes. These alliances can unlock innovative solutions to local polymer design challenges, improve product performance, and reduce R&D costs. Policymakers and industry leaders must recognize CFD as a strategic enabler of research efficiency, innovation, and sustainable industrial development. Consequently, its integration into Nigeria's national science, technology, and innovation (STI) frameworks is imperative [65, 66].

To ensure tangible impact, policymakers—particularly those within the Federal Ministry of Science, Technology and Innovation, NITDA, and TETFund—should embed CFD initiatives into national STI strategies and funding instruments. A phased implementation strategy is recommended: in the short term, prioritize curriculum updates and pilot training programs; in the medium term, support software licensing, cloud-based HPC infrastructure, and interdisciplinary grants; and in the long term, drive industrial-scale applications and R&D commercialization. Periodic monitoring and evaluation should be institutionalized to track uptake, measure outcomes, and assess the return on investment (ROI) of CFD-integrated research efforts.

CONCLUSIONS AND OUTLOOK

This study has articulated the critical role that Computational Fluid Dynamics (CFD) can play in transforming polymer research in Nigeria. Drawing upon an extensive review of existing literature, the findings reveal a pronounced gap: polymer research within the country continues to rely heavily on traditional laboratory experimentation, with limited adoption of CFD tools and techniques. This underutilization constrains the ability of researchers to explore complex fluid and thermodynamic behaviors inherent in polymer systems, thereby limiting innovation and efficiency.

In light of this, it is strongly recommended that future polymer research in Nigeria incorporates CFD methodologies as a complementary or alternative approach to experimental procedures. The integration of CFD offers several advantages: enhanced understanding of transport phenomena, predictive modeling of process parameters, reduction of experimental costs, and acceleration of polymer design and optimization processes.

To ensure successful implementation, research institutions should prioritize curriculum development, capacity building, and access to simulation software and high-performance computing resources. Moreover, strategic partnerships between academia, industry, and government will be essential to translate CFD insights into tangible product and process innovations. As Nigeria advances its national science and innovation agenda, embedding CFD within policy frameworks and funding mechanisms will be vital for sustaining long-term research excellence and industrial relevance in polymer science.

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