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Artificial Intelligence (AI) Options in the Establishment of Computer Aided Process Equipment Design (CAPED) Simulation Laboratory

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ABSTRACT

The invention of Artificial Intelligence (AI) technologies has revolutionized various industrial unit operations and the whole processes; this includes the designs of process equipment and automation. This paper explores the potential applications of AI in the establishment of Computer-Aided Process Equipment Design (CAPED) simulation laboratories in Nigeria. CAPED aides the designs and optimization of process equipment using the application of computational simulations which assist the engineers and technologists to arrive at informal decisions that is credible, concise, accurate, economical and satisfactory. By integrating AI techniques such as machine learning, deep learning, data fusion and natural language processing, CAPED simulation laboratories can enhance efficiency, accuracy, and innovation in the design of process equipment. This paper discusses the utilization of AI algorithms for data-driven modeling, predictive analytics, optimization, and decision support within CAPED environments. Furthermore, it explores the challenges, opportunities, and future prospects associated with the integration of AI in CAPED simulation laboratories, highlighting the potential to streamline design workflows, reduce costs, improved efficiency, concise and accelerate innovation in process equipment engineering. Therefore paper further addressed the problems of non-establishment of simulation laboratories in the PTDF centers of Excellence in Port Harcourt and Kaduna respectively. The solution mechanism is the adequate provision of policy framework and facilities to drive the CAPED team under the new technological innovations and inventions. This paper is useful for innovations and administrations to improve management decisions.

Keywords: Simulations, CAPED, 3D Printing and Scanning, Artificial Intelligence, Machine Learning

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INTRODUCTION

The concept of the CAPED project is to develop simulation software suites for design of process equipment and plants to compliment unit operations in the process industry, which are large and in-exhaustive. CAPED project is targeted at mitigating the problems inherent in locally fabricated equipment by local road side fabricators and some engineers resulting from partial or non-applications of design procedures. This is an engineering and technological corrective measure to establish the strong position of the PTDF in local content development programs of the federal government of Nigeria, and also validate the creation of the new Department of Research and Innovation Technology, adding value to locally available raw materials and capacity building in the country (Neeka et al 2023). Process simulation is a model-based representation of chemical, physical, biological, and other technical processes and unit operations that are inputted in software. Basic prerequisites involve a thorough knowledge of chemical and physical properties of pure components and mixtures, reactions, and mathematical models which in combination allow the calculation of any process using computational simulations. Process simulation software are connected with the description of process flow schemes (PFSs) where every unit operations are described, positioned and connected by product streams (Idris 2014). The simulation software has to solve the mass and energy balance to arrive at optimum operating conditions (Idris 2014 and Idris et al., 2015). The central goal of all process simulation is to find optimal conditions for an examined process. This is essentially an optimization problem which has to be solved in an iterative process (experimental simulation). Process simulation always uses models which introduce approximations and assumptions, but allow the description of a property over a wide range of temperatures, pressures, mass or molar concentration etc., which might not be covered by real data (Idris et al., 2015). Models also allow interpolation and extrapolation - within certain limits - and enable the search for conditions outside the range of known properties. The development of models for a better representation of real processes is the core of the further development of the simulation software. Chemical engineering field carry out the model development, while the control engineers execute the improvement of mathematical simulation techniques. Process simulation is therefore one of the few fields that requires an extensive collaborations of the scientists from chemistry, physics, computer science, mathematics, and several engineering fields work together. Dynamic simulation is an extension of steady-state process simulation whereby time-dependence is built into the models via derivative terms i.e. accumulation of mass and energy (Idris et al., 2015). The advent of dynamic simulation means that the time-dependent description, prediction and control of real processes in real time have become possible. This includes the description of starting up and shutting down a plant, changes of conditions during a reaction, holdups, thermal changes and more. Dynamic simulations require increased calculation time and are mathematically more complex than a steady state simulation. It can be seen as a multiply repeated steady state simulation (based on a fixed time step) with constantly changing parameters. Dynamic simulation can be used in both an online and offline fashion. The online case being model predictive control, where the real-time simulation results are used to predict the changes that would occur for a control input change, and the control parameters are optimised based on the results. Offline process simulation can be used in the design, troubleshooting and optimisation of process plant as well as the conduction of case studies to assess the impacts of process modifications. Dynamic simulation is also used for the training of operators, and at their learning stage they use the demo-real life process plant and in the end use the industrial versions when they become an expert in the software usage (Idris et al., 2016a). New products always require new processing equipment and the design of these new equipment must be brought to the fore before fabrication of such equipment are made. It is also possible that existing plants may require being scaled up to meet up with the market product requirements, quality standards etc. All these will require virtual redesigning using a simulation software suite. The desired result achieved is then transferred to the real process to effect the needed changes of process variables that will satisfy the demands. All 3D model designs can be printed using a 3D printer to actualize the design in real life. Existing models can be 3D scanned, simulated and printed using a 3D scanner. On the above note however, the scope of the CAPED project is as large and in-exhaustive as the numerous unit operations.

A simulation software package allows process designers the opportunity to play around with process variables real-time and observe behavioral changes of the process stream based on the changes of the process variables. This is a good opportunity for successful scale-ups of existing plants and high accuracy in new process/equipment designs. In a virtual environment, it is much easier to change parameters, such as load and excitation, but also system properties, than under real conditions. This enables you to try out a great number of various options with the help of system simulation in no time. Virtual modeling can help you calculate and visualize also complex systems as a dedicated simulation software is specially designed for this very purpose. The user interface, the modeling process and the result analysis of such development tools are optimized for simulating multiphysics systems. The solver algorithms are especially suited for physical equations and can thus deal also with nonlinear equation systems. System simulation helps you increase performance and energy efficiency of your product, optimize vibrational behavior, reduce potential risk to health and safety and back up planned investments. Simulations help you master vibrations in the powertrain and thus help increase not only the level of precision of your machine. Another advantage is the noticeably smoother operation of the machine. Apart from insulation, a reduced level of vibration is the most effective way for lower noise emissions. Once you know the behavior of your machine under extreme conditions, you can take appropriate measures for the safety of human lives and of your machinery (Idris et al., 2016b). Virtual system simulation permits tests for the most extreme situations without putting health and safety of human lives at risk. Moreover, virtual testing offers considerable saving potentials compared to real test scenarios. The sustainability of the CAPED is guaranteed as human capacity to drive the project is identified and readily available. Apart from producing additional software suites for other universal components used in the industry, it is being envisaged that fabrication of a universal drier (spray drier) whose software suites was done (Christopher et al 2022), be expanded and the application of the Artificial Intelligent component introduced to enhance the much anticipated innovative component of the new invention, which the Fund holds intellectual property.

2.0 METHODS AND MATERIALS

Additive manufacturing (AM) encompasses methods of fabrication that build objects through the successive addition of material, as opposed to subtractive methods such as computer numerical control (CNC) machining that remove material until a final shape is achieved. Composite fabrication is one of the most original forms of additive manufacturing. Whether the process involves wet lay-up, hand lay-up of prepreg materials, or automated fiber placement (AFP), methods of composite manufacture are distinctly additive in nature; building up to final part forms typically one layer at a time. However, the nature of additive manufacturing has been revolutionized with the advent of the 3D printing industry. Over the past decades, 3D printing technologies have advanced rapidly and recently reached a state of mainstream adoption, particularly for rapid prototyping. Such technologies are only beginning to penetrate and influence the advanced composites industry, although the AM industry is clearly approaching a tipping point where the impact on the composites industry is expected to become as broad and significant as that in prototyping.

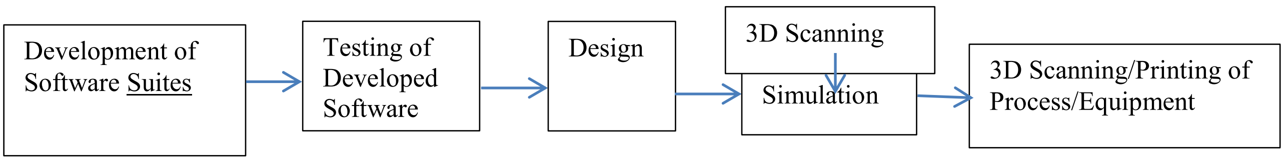

Figure 1: Project Network Diagram.

2.1 MATERIALS, CHARACTERISTICS AND CONSIDERATIONS

From a functional perspective, the use of additive manufacturing for composite mold tooling is not that dissimilar from conventional approaches. Just as design and construction aspects of conventional lay-up tooling varies depending on the material used (e.g. tooling board, aluminum alloys, Invar, graphite/epoxy, etc.), there are a number of considerations to keep in mind for effective design and use of additively manufactured composite tool molding. The primary considerations for fused deposition modelling (FDM) tooling in particular are as follows:

2.1.1 Cure Temperature: The cure temperature of the composite material will directly influence material selection. There is a range of high-temperature FDM materials available, several with a glass transition temperature in excess of 2000C that can be used effectively at common high-performance composite cure temperatures (typically 1800C). Polyetherimide (PEI) and polyethersulfone (PES) are two such high-temperature thermoplastics that are well-suited to the application due to their high heat resistance and stability.

2.1.2 Coefficient of Thermal Expansion (CTE): CTE is an important consideration for nearly all mold tooling applications since it impacts the final physical shape (and often the performance) of the composite structure. FDM is capable of using materials with and without reinforcement (such as fibers) and fillers (such as glass beads, silica, carbon nanotubes, and many others). The presence or absence of such constituents has a significant impact on the resulting CTE of the tool. Unfilled/ unreinforced thermoplastics tend to have a relatively high CTE, but even modest loading levels of reinforcing fibers can drastically reduce thermal expansion. Tool designs can and typically should be modified to compensate for the dimensional changes related to thermal expansion at elevated temperatures. In addition to geometric compensation, CTE differences between the tool and part materials are also factors that impact tool type (male versus female tools) and potential complexity.

2.1.3 Process Parameters (consolidation pressure and vacuum bagging approach): Fabrication process (e.g., hand lay-up, automated fiber placement (AFP), resin transfer molding machine (RTM), compression molding etc.) and cure cycle parameters, particularly cure pressure and vacuum bagging method (i.e., envelope vs. edge/surface bagging), impact the design approach of mold tools built with FDM technology. With proper design, printed molds are able to withstand the high pressure (0.7 MPa) autoclave cycles common to high-performance composite materials or even the much higher pressure levels used for RTM and compression molding.

2.2 TOOL DESIGN

One major benefit of Additive Manufacturing (AM) for composite mold tooling is the ability and freedom to tailor the tool design specifically to the application. For instance, a schedule-critical repair tool intended to produce one to two parts can be optimized for rapid build time whereas a mold intended for longer-term production use requires greater scrutiny in nearly all aspects and can be designed and built accordingly. The design process for an FDM tool is primarily driven by the process parameters for the final composite parts (e.g. cure cycle, pressure, bagging approach, etc.), as previously discussed. A pictorial representation of CNC machine is depicted in Figure 2.

Figure 2: Computer numerical control (CNC) machine

2.3 FUSED DEPOSITION MACHINE (FDM)

FDM composite tooling designs can be as complex, simple, or functionally oriented as the application requires. And in general, there is virtually no additional cost for complexity when using AM technologies. With AM, no longer is a designer or engineer required to solely “design for manufacturability.” Rather, there is a need, or freedom, to take a completely different perspective, referred to as “design for additive manufacturing” (DFAM). DFAM enables enormous flexibility and can be thought of more as a mindset than a strict set of rules. AM technologies can generally build any shape or design that is rendered (within limits that vary based on the technology of course), but there are still methods to most efficiently use material, minimize waste and build time, enhance functionality or performance, and numerous other aspects. These concepts can be applied to both parts and tooling to produce highly optimized results with many performance benefits.

Figure 3: Numerical control design of composite system.

2.4 PRINTED TOOLING VS. CONVENTIONAL TOOLING

The benefits of technologies such as FDM for mold tooling and other ancillary tools have been touched on throughout. AM provides unparalleled design freedom, which permits tailoring designs specifically to the relevant use case or application. For mold tooling, this typically results in significant reductions in lead times, levels of touch labor, and cost. Such benefits are also important in that they subsequently enable additional design iteration, optimization, and the ability to incorporate changes much later in the product development cycle.

Figure 4: Application for composite fabrication system

3.0 RESULTS AND DISCUSSION

It is imperative to note that 3D scanners are used to capture 3D shapes of objects in real life. CAPED/DFAM software are then used to design the object giving considerations to all the dimensions. The combined use of 3D scanning and 3D printing technologies allows the replication of real objects without the use of traditional designing and redesigning techniques that in many cases can be too invasive for being performed on precious or delicate cultural heritage artifacts. In an example of a typical application scenario, a gargoyle model was digitally acquired using a 3D scanner and the produced 3D data was processed using MeshLab. The resulting digital 3D model was fed to a rapid prototyping machine to create a real resin replica of the original object. This procedure can be applied to all objects in automobile, aircraft, ship etc. The digitalization of real-world objects is of vital importance in various application domains. This method is especially applied in industrial quality assurance to measure the geometric dimension accuracy. Industrial processes such as assembly are complex, highly automated and typically based on CAD (Computer Aided Design) data. The problem is that the same degree of automation is also required for quality assurance. It is, for example, a very complex task to assemble a modern car, since it consists of many parts that must fit together at the very end of the production line. The optimal performance of this process is guaranteed by quality assurance systems. Especially the geometry of the metal parts must be checked in order to assure that they have the correct dimensions, fit together and finally work reliably. Within highly automated processes, the resulting geometric measures are transferred to machines that manufacture the desired objects. Due to mechanical uncertainties and abrasions, the result may differ from its digital nominal. In order to automatically capture and evaluate these deviations, the manufactured part must be digitized as well. For this purpose, 3D scanners are applied to generate point samples from the object's surface which are finally compared against the nominal data. The process of comparing 3D data against a CAD model is referred to as CAD-Compare, and can be a useful technique for applications such as determining wear patterns on molds and tooling, determining accuracy of final build, analyzing gap and flush, or analyzing highly complex sculpted surfaces. At present, laser triangulation scanners, structured light and contact scanning are the predominant technologies employed for industrial purposes, with contact scanning remaining the slowest, but overall most accurate option. Nevertheless, 3D scanning technology offers distinct advantages compared to traditional touch probe measurements. White-light or laser scanners accurately digitize objects all around, capturing fine details and freeform surfaces without reference points or spray. The entire surface is covered at record speed without the risk of damaging the part. Graphic comparison charts illustrate geometric deviations of full object level, providing deeper insights into potential causes.

3D Scanning can be used in conjunction with 3D printing technology to virtually teleport certain object across distances without the need of shipping them and in some cases incurring import/export tariffs. For example a plastic object can be 3D scanned in the United States, the files can be sent off to a 3D printing facility over in Germany where the object is replicated, effectively teleporting the object across the globe. In the future, as 3D scanning and 3D printing technologies become more and more prevalent, governments around the world will need to reconsider and rewrite trade agreements and international laws.

3.1 PROPOSED PROJECT ACTION

Apart from producing additional software suites for other universal components used in the industry, free hand process equipment design and fabrication is cumbersome and time consuming. The global trend in both developed and developing countries is to develop simulation software packages for design of process equipment and plants. A simulation software package allows process designers the opportunity to play around with process variables real-time and observe behavioural changes of the process variables. This is a good opportunity for successful scale-ups of existing plants and to achieve high prescition and accuracy in developing new process equipment designs. Moreover, it is easier to change parameters such as load and excitation in a virtual environment than under real conditions. This enable the designer to try out varities of design options with the help of the system simulator in real time. Virtual modeling can help the designer to calculate and visualize complex systems as a dedicated simulation software is specially designed for the specific purpose.

The user interface, modeling process and the result analysis of such development tools are optimized for simulating multiphysics systems. The solver algorithms are specially suited for physical equations and can thus deal with nonlinear equations. Discrete networks and graphical user interface will keep the model logically structured and easy to work with. System simulation helps to increase performance and energy efficiency and output, optimize vibrational behavior, reduce potential risk to health and safety and back up planned investments. Simulation also help the designer to master vibrations in the power train and thus help to increase the level of precision of the machine. Another advantage is the noticeable smoother operations of the machine and lower noise emissions per time.

Table 1: Project Risk Matrix

Risk	Impact	Probability	Mitigation
Inadequate Funding	Project Suffers Progression	Project slow pace	Adequate and Timely Funding

Table 2: Five steps developed activities for the spray dryer.

PTDF and CEFPACS.	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Activity 5 etc.**
CAPED Team	Software Suite Dev	Testing with Literature data	Validating software using Process Data	Design of Process/Equip-ment	Fabrication of Designed process/Equipment

Table 2 depicts the sequential steps used to achieve the set-objectives and successful use of the CAPED simulator by the in-house team, produce technical report writing and communicate the whole message to the management. In an efficient team work proceedings, there are quarterly schedules and updates on the progress of the project work.

Table 3: Sequential steps to achieve target objectives from table 1

Method: Trainig Workshops and Seminars	**Audience (Who will Receive the Message)**	**Message (What is the Topic)**	**Communicator (Who is Delivering the Communication)**	**Schedule (When and How Often will this take place)**	**Status (Update on Communication to date)**
Technical Report Writing	Management	CAPED Simulation	CAPED In-House Team	Quarterly	Quarterly Updates

3.2: EXPECTED PROJECT OUTCOME

Development of simulation software suites for design of process equipment and plants to provide accurate design of process equipment and plants which will be translated into fabrication within the domain of 3D printing and 3D scanning in order to nutralize the problems of inefficiancy, low quality of products etc., which are inherent in local fabrication caused by non application of design procedures. Quarterly meetings in the Headquarters to produce additional software suite for other process equipment as well as periodic programme demonstration exercise of the produced software and also 3D printing of 3D designs carried out in the simulation laboratory. Regular quarterly design meetings and adequate funding including the involvement of critical stakeholders such as researchers, resource persons and scholars in the ICT sectors. Once the behavioral pattern of the machine is established even under extreme conditions, measures can be put in place to provide safety of human lives and machinery equipments. Virtual system simulation permits test for the most extreme situations without putting health and safety of human at risk. Moreover, virtual testing offers considerable saving potentials compared to real test scenarios. Simulation comes with convinient tools for such purposes in order to track and analyze effects of failures in details. This enables the designer and user of the model to evaluate the real benefit of redundant components and identify the most influential factors on the system's safety and reliability code. 3D produced designs can be printed life on a tray with exact dimentions and properties as provided by mathematical data and design algorithms. Existing products that need to be reproduced can be scanned via 3D in a 3D and printed immediately. Machine spare parts can be produced accurately and instantly for the intended purposes.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1: CONCLUSIONS

In conclusion, the project flow scheme (PFS) is captured in Figure 2. Starting with development of the software suites, testing the developed version, actualising the design and followed by simulation, and finally achieving the 3D scanning/ printing equipment. The product quality and specifications conform to global standards. Products were found to be intelligent, interactive and user friendly. The conformity of the product to literature data is remarkable. This would be improved with the introduction of 3D scanning and 3D printing.

4.2: RECOMMENDATIONS

Within the limit of experimental work, it is recommended that inadequate funding will pose the high risk of achieving the set-objectives. The project will equally sufer a set-back with non- achievable task at the appropriate time. Therefore, a mitigation methods should be initiated for adequate provision of funds within the stipulated time and as prompt as possible as shown in Table 1 above.

ABBREVIATIONS

AFP	-	Automated fiber placement
AI	-	Artificial intelligence
CAD	-	Computer Aided Design
CAPED	-	Computer-Aided Process Equipment Design
CNC	-	Computational numerical control
CTE	-	Coefficient of thermal expansion
DFAM	-	Design for additive manufacturing
FDM	-	Fused deposition modelling
ICT	-	Information and communication technology
PFS	-	Project flow scheme
PTDF	-	Petroleum technology development fund
PEI	-	Polyetherimide
RTM	-	Resin transfer molding machine

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