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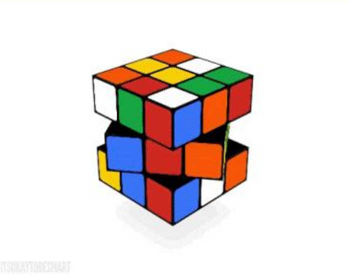
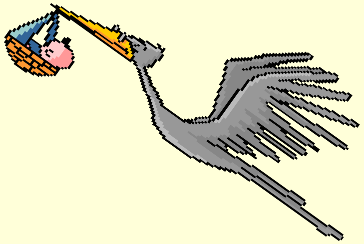


Fluids and Plasma Physics: Research Trends and Challenges in Africa



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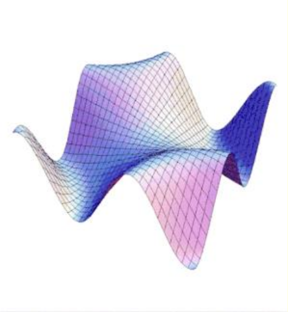
Presentation Overview



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Introduction: Fluid Description of Plasma

Plasma phenomena can be explained by a fluid model, in which the identity of the individual particle is neglected, and only the motion of fluid elements is taken into account

The theoretical study of plasma as a fluid is governed by the concept of magnetohydrodynamics (MHD) which involved a combination of conservation equations of conducting fluid mass, charges and momentum coupled with state equation and Maxwell equations of electromagnetism

Plasma may involve the dynamics **positively charged ion fluid** and **negatively charged electron fluid**. In a partially ionized gas, the dynamics of **fluid of neutral atoms** may also be involved. The neutral fluid will interact with the ions and electrons only through collisions. The ion and electron fluids will interact with each other even in the absence of collisions due to the generation of the electric and magnetic fields

Introduction: Some Plasma Properties

Mass density $\rho_m = n_e m_e + n_i m_i$

Charge density $\sigma = q_e n_e + q_i n_i$

Mass velocity $V = (n_e m_e v_e + n_i m_i v_e) / \rho_m$

Current density $\mathbf{j} = q_e n_e v_e + q_i n_i v_i = q_e n_e (v_e - v_i)$

Total pressure $p = p_e + p_i$

where the subscripts *i* and *e* represent the ions and electrons, respectively.

Magnetohydrodynamics (MHD) Equations for Plasma

(1) $$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (nV) = 0,$$ (Mass Conservation Equation)

(2) $$\frac{\partial \sigma}{\partial t} + \nabla \cdot (n\mathbf{j}) = 0,$$ (Charge Conservation Equation)

(3) $$\underbrace{\rho_m\left(\frac{\partial V}{\partial t} + \mathrm{V}\cdot\nabla V\right)}_{\substack{\textit{rate}\text{ of change of} \\ \text{total momentum density}}} = \underbrace{\sigma E}_{\substack{\textit{Electric} \\ \text{body force}}} + \underbrace{\mathbf{j}\times B}_{\substack{\textit{Magnetic}\text{ force} \\ \text{on current}}} - \underbrace{\nabla P}_{\text{Pr}\textit{essure}},$$ (Momentum Equation)

or $$\rho_m\left(\frac{\partial V}{\partial t} + \mathrm{V}\cdot\nabla V\right) = \sigma(E + V\times B) - \nabla P + \rho_m F, \qquad F = -\upsilon_{jk}(v_j - v_k),$$

Maxwell Equations

(4) $$\nabla\times B = \mu_0 \mathbf{j} + \frac{1}{c^2}\frac{\partial E}{\partial t}, \quad \nabla\times E = -\frac{\partial B}{\partial t},$$

$$\nabla\cdot B = 0, \ \nabla\cdot(\in_0 E) = \sigma, \quad E + V\times B = \eta\mathbf{j} + \frac{\mathbf{j}\times B - \nabla p_e}{ne},$$

where B is the magnetic field strength, E is the electric field, n is the particle density and η is the resistivity.

Equation of state (EOS)

- An equation of state is a thermodynamic equation describing the state of matter under a given set of physical conditions.

$$p = p(n, T), \qquad \varepsilon = \varepsilon(n, T)$$

- Isothermal EOS for slow time variations, where temperatures are allowed to equilibrate. In this case, the fluid can exchange energy with its surroundings.

$$\boxed{p = nkT, \qquad \nabla p = kT\nabla n} \qquad n_{\mathrm{g}}\,(\mathrm{cm}^{-3}) \approx 3.250 \times 10^{16}\, p\,(\mathrm{Torr})$$

→ The energy conservation equation needs to be solved to determine *p* and *T*.

- Adiabatic EOS for fast time variations, such as in waves, when the fluid does not exchange energy with its surroundings

$$\boxed{p = Cn^{\gamma}, \qquad \frac{\nabla p}{p} = \gamma \frac{\nabla n}{n}} \qquad \gamma = \frac{C_p}{C_v} \quad \text{(specific heat ratio)}$$

→ The energy conservation equation is not required.

- Specific heat ratio vs degree of freedom (f) $\qquad \gamma = 1 + \dfrac{2}{f}$

Status of Fluids and Plasma Physics Internationally

Below is a compilation of research initiatives shaping fluids and plasma physics internationally.

- **Fusion Energy Projects**: ITER in France exemplifies global collaboration in plasma physics, aiming for breakthroughs in sustained nuclear fusion. Tokamak upgrades in China (EAST) and the UK (JET) are also pivotal in advancing plasma confinement techniques.
- **Space and Astrophysical Plasmas**: Research into cosmic plasmas explores magnetic reconnection, solar wind turbulence, and shock waves in interstellar environments. Missions like NASA's Parker Solar Probe provide valuable empirical data.
- **Biomedical Applications**: Plasma medicine uses non-thermal plasmas for wound healing, cancer treatment, and sterilization, with researchers leveraging interdisciplinary insights from physics and biology.
- **Environmental and Industrial Fluids**: Studies on turbulent flows, pollutant dynamics, and aerodynamics drive progress in environmental management and transportation efficiency.
- **Computational Fluid and Plasma Dynamics**: Machine learning aids in the resolution of Navier-Stokes equations and plasma turbulence models, leading to more accurate simulations for practical applications.

Research Centers and Global Collaborations

- **Max Planck Institute for Plasma Physics (Germany)**: Leads in experimental and theoretical plasma studies.
- **Lawrence Livermore National Laboratory (USA)**: Focuses on high-energy-density plasmas.
- **Korea Superconducting Tokamak Advanced Research (KSTAR)**: Innovates in plasma confinement.

Status of Fluids & Plasma Physics In Africa

Fluids and plasma physics research in Africa is a growing field characterized by efforts to address region-specific challenges, including energy generation, environmental sustainability, and industrial development

- The research is supported by universities, research institutions, and international initiatives aiming to strengthen the continent's scientific infrastructure. Areas of focus include magnetohydrodynamics (MHD), computational fluid dynamics (CFD), plasma physics for renewable energy, and practical applications such as agricultural processing, healthcare, and environmental protection.

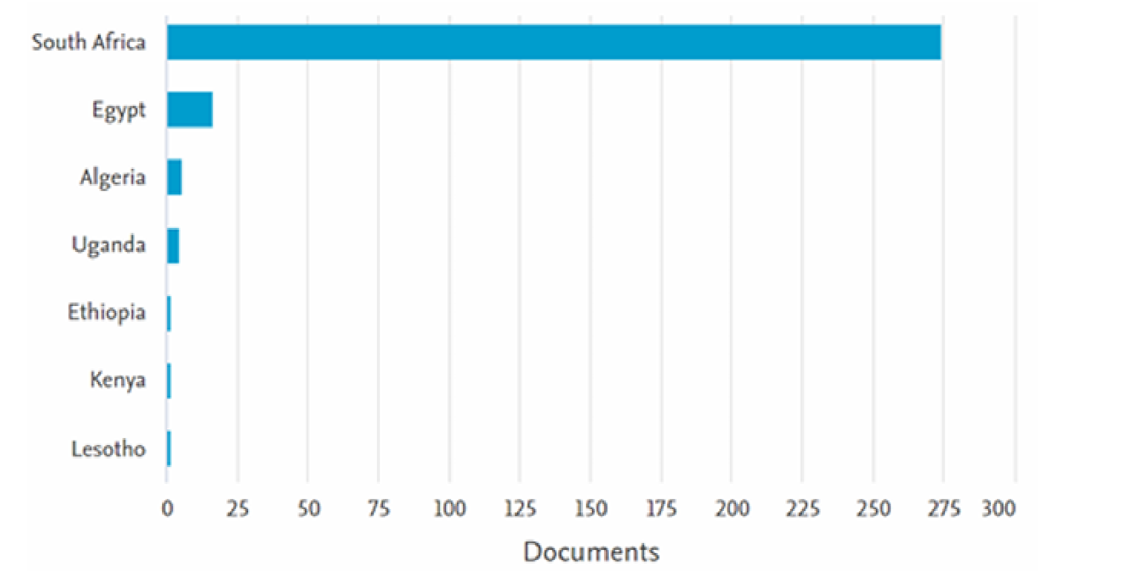

Figure *Fluids and plasma physics research output in Africa (source-SCOPUS database)*

Status of Fluids & Plasma Physics In Africa

South Africa

- South Africa is a leading nation in Africa for plasma physics and fluid dynamics research. It hosts advanced facilities and collaborates internationally on plasma applications and CFD.
- South Africa is contributing to astrophysical plasma studies through collaborations with global space agencies.
- The **South African National Space Agency (SANSA)** explores the behavior of space plasmas, particularly their interaction with the Earth's magnetosphere and ionosphere.

Egypt

- Egypt's research in fluid mechanics focuses on applications in agriculture, desalination, and energy systems.
- Universities like Cairo University and Alexandria University conduct plasma physics research, often in collaboration with European institutes.

Nigeria

- Nigeria's contributions include work on low-temperature plasma for industrial and environmental applications.
- Research institutions focus on practical fluid mechanics for industrial and agricultural improvements.

North Africa

- Countries like Morocco and Algeria are integrating computational fluid dynamics into renewable energy projects, such as optimizing wind turbine designs and solar panel cooling systems.

African Participation in ITER Research

African participation in the International Thermonuclear Experimental Reactor (ITER) research project is emerging as a critical avenue for building capacity in nuclear fusion and plasma physics. The main goal of ITER is to achieve a sustained fusion reaction where the energy output exceeds the energy input, paving the way for future fusion power plants.

Located in southern France, ITER is a collaborative effort involving 35 countries, including the European Union, the U.S., China, Russia, Japan, India, and South Korea.

- South Africa is the primary African nation actively involved in ITER-related research and initiatives
- **National Research Foundation (NRF)** and South African universities collaborate with ITER member countries to align research priorities. South African physicists work on plasma diagnostics, magnetohydrodynamics (MHD), and material science relevant to ITER.

Benefits of Participation in ITER for Africa

- **Technological Advancement:** Access to cutting-edge technologies, including high-performance computing and advanced materials, enhances Africa’s scientific and industrial capabilities.
- **Energy Security:** Involvement in ITER equips Africa with the expertise to adopt fusion energy technologies when they become commercially viable.
- **Human Capital Development:** Training programs and international collaborations develop a new generation of African scientists specializing in fusion energy.

Fluids & Plasma Physics Education in Africa

Fluids and plasma physics are integral to advancing scientific understanding and technological innovation. In Africa, these fields hold significant potential for addressing energy, environmental, and industrial challenges. However, realizing this potential requires targeted efforts in education and capacity development to overcome existing barriers.

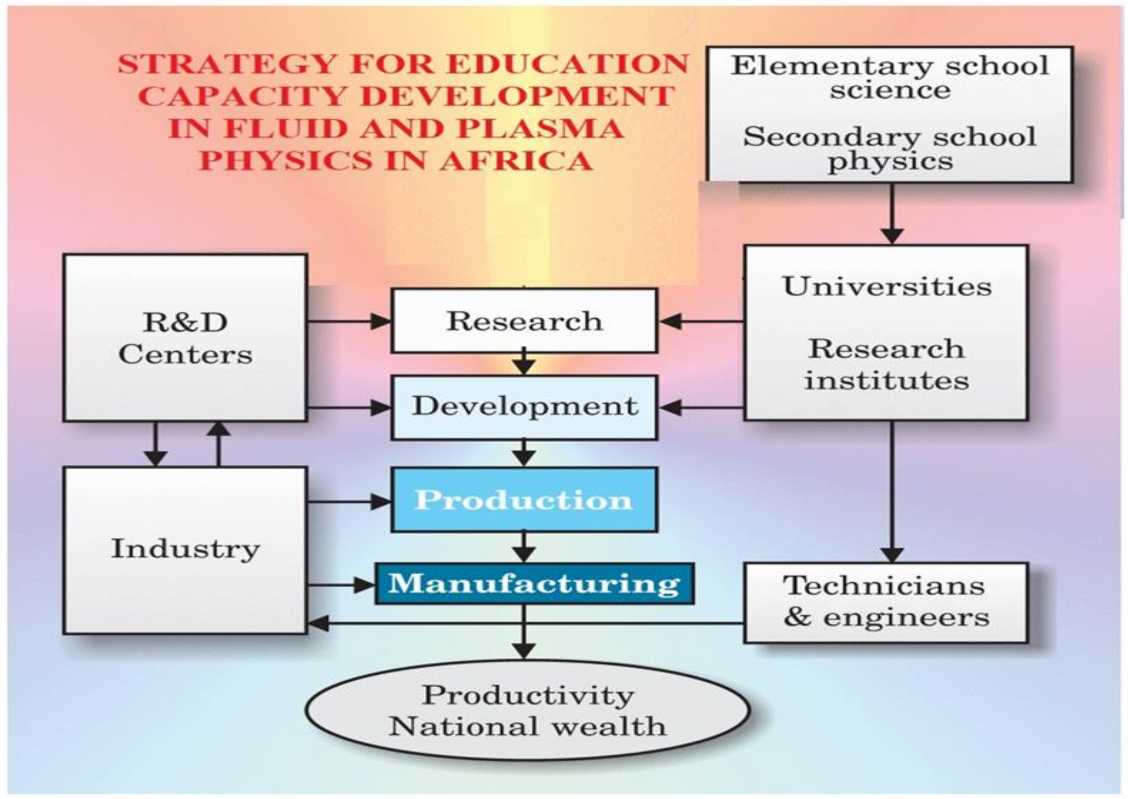

Figure *Strategy for education capacity development in fluid and plasma physics in Africa*

Challenges Facing Fluids & Plasma Physics in Africa

1. Limited Funding and Infrastructure

- **Lack of Resources**: Many institutions struggle with funding for laboratories, experimental setups, and computing resources.
- **Insufficient Research Facilities**: Few African nations have advanced plasma research facilities, such as tokamaks or wind tunnels.
- **Brain Drain**: Talented scientists often relocate to developed nations for better opportunities, creating a knowledge gap.

2. Fragmented Regional Collaboration

- **Lack of Coordination**: Limited collaboration between African nations hinders the development of cohesive research and education strategies.
- **Underutilization of Pan-African Frameworks**: Programs like the African Union's Science and Technology initiatives are not fully leveraged.

3. Curriculum Gaps

- **Lack of Specialized Courses**: Few African universities offer advanced degrees specifically in fluids or plasma physics.
- **Limited Industry-Academia Linkages**: Curricula often lack practical training relevant to industry needs.

4. Awareness and Advocacy

- **Low Public and Policy Awareness**: The importance of fluids and plasma physics is not well-recognized by policymakers or the public.

Recommendation and Conclusion

1. **Increase Funding**:
   - Governments and private sectors must invest in infrastructure, scholarships, and faculty development programs.
2. **Develop Specialized Curricula**:
   - Introduce dedicated undergraduate and postgraduate courses in plasma physics, computational fluid dynamics, and applied mechanics.
3. **Promote Regional Cooperation**:
   - Establish African networks for plasma and fluid physics to foster collaboration and resource sharing.
4. **Leverage International Expertise**:
   - Invite experts to conduct workshops, seminars, and joint research projects.
5. **Raise Awareness**:
   - Highlight success stories and applications of these fields to inspire the next generation of researchers.

Recommendation and Conclusion

6. Expanding Collaborative Networks

- Strengthening partnerships with global research projects, such as ITER, CERN, and IAEA programs, provides African students access to cutting-edge research and training.

7. Building Regional Centers of Excellence

- Establishing hubs for plasma and fluid physics can create focal points for research, training, and resource sharing.

8. Enhancing Digital Access

- Utilize MOOCs, virtual labs, and AI-powered learning platforms to reach students across the continent.
- Partner with international platforms to provide free or subsidized access to educational content.

10. Policy and Advocacy

- Governments must recognize the strategic importance of these fields by allocating funding and creating scholarships.
- Promote these fields as career pathways by showcasing their impact on energy, health, and technology sectors.

11. Industry Integration

- Encourage partnerships with industries to develop internship programs and industry-sponsored research projects.

REFERENCES

[1] A. R. Choudhuri, The physics of fluids and plasmas: An introduction for Astrophysics. Cambridge University Press, Cambridge, 1998.

[2] F. F. Chen, Plasma Physics and Controlled Fusion, 2nd ed. Springer, New York, 2006.

[3] R.O. Dendy, Plasma Physics: An introductory course. Cambridge University Press, Cambridge, 1993.

[4] J. Boyd and J.J. Sanderson, The physics of plasmas, Cambridge University Press, Cambridge, 2003).

[5] P. A. Davidson, An introduction to magnetohydrodynamics. Cambridge University Press, 2010.

[6] P. Gibbon, Short Pulse Laser Interactions with Matter: An Introduction (Imperial College Press, London, 2005). http://dx.doi.org/10.1142/p116

[7] J. D. Jackson, Classical Electrodynamics, 2nd ed. (Wiley, New York, 1975), 3rd ed. (Wiley, New York, 1998).

[8] J. P. Dougherty, in Plasma Physics, Ed. R. Dendy (Cambridge University Press, Cambridge, 1993), Chap. 3.

[9] M. Abdollahzadeh, J. C. Pascoa, P. J. Oliveira, Implementation of the classical plasma-fluid model for simulation of dielectric barrier discharge (DBD) actuators in OpenFOAM Comput. Fluids 128 77–90, 2016.

10] https://www.scopus.com/

11] The Association of Commonwealth Universities and Institute of Physics. Africa-UK Physics Partnership Programme Feasibility Study Report (2020). doi: https://www.acu.ac.uk/media/3533/feasibility-study-report-final.pdf.

12] African Union. Innovating Education in Africa Initiative (2018). doi: https://au.int/en/pressreleases/20181005/innovation-education-africa-expo-2018- kicked-today.

THE END

THANK YOU VERY MUCH

ALL THE BEST AND GOD BLESS