Anatomizing Thermophysical Properties of Atmospheric Gases (N_2, O_2, Ar, CO_2) for Energy Generation, Environmental Protection, and Chemical Conversion: A Review

Andrew Koko Wejlah

School of Safety Engineering, China University of Mining and Technology, Xuzhou, China. Email: kokowejlah96@gmail.com

KEYWORDS
Atmospheric Gases, Thermophysical Properties, Energy, Environment, Chemistry

ABSTRACT
The thermophysical properties of atmospheric gases are crucial for understanding their behavior in various applications. This paper provides an overview, highlighting control and utilization mechanisms of major atmospheric gases (N_2, O_2, Ar, and CO_2) for energy generation, mitigation for environmental protection, and transformations in chemical reactions or systems. The top three atmospheric gases in terms of concentration, N_2 78.084%, O_2 20.946%, and Ar 0.934% were selected along with the most prevalent greenhouse gas, CO_2 0.041%. In addition, CO_2 is an essential gas used by plants and other organisms. The diffusion coefficient reflects the behavior (mixture properties) of the gases. Thermal energy conversion, combustion process, carbon capture and storage for greenhouse gas mitigation, absorption catalysis, synthesis, etcetera are media for applications analyzed from properties such as density, viscosity, specific heat, and thermal conductivity. These basic concepts and more, as stipulated in this paper, will provide a basis through which a sustainable and efficient research path involving atmospheric gases (composition in mixtures such as air and utility potential in applications) can be calved by current and future researchers.

1. Introduction:

Concentrations of atmospheric gases are typically quoted in terms of dry air (without water vapor).[1] Water vapor accounts for roughly 0.25% of the atmosphere by mass.[2] When analyzing atmospheric and greenhouse gases in an effort to attain climate solutions, their increasing concentrations remain a significant topic of discussion amidst climate crisis and impact potential beyond their atmospheric local seeking divergence as a solution technique. Due to gravity, layers of gases surround the earth's outer layer, i.e., the earth's atmosphere supporting life on Earth. Nitrogen, the most dominant of these gases, dilutes oxygen and prevents rapid or instantaneous burning on the Earth's surface. Oxygen gas is a major component of the combustion triangle and provides life support on Earth.[3] . From the aforementioned, oxygen is a threat and savior as per utility; as such, it should be treated with severe caution. Argon is a noble gas (non-reactive) that has the propensity to displace oxygen in confined places, leading to asphyxiation. Elements present in the earth's atmosphere determine air composition. Air composition can be influenced by altitude, location, and human activities with thinner air and low oxygen concentration at higher altitudes.[4] Air pollution is common in urban areas due to human activities. Understanding the impacts of human activities on the environment and implementing measures to improve air quality requires ardent monitoring of air composition.

Heat absorbed by atmospheric gases is re-radiated in all directions. Some escape into space, but a portion returns to the earth and is reabsorbed, thus raising its temperature, resulting in greenhouse effect. If an infrared-absorbing gas such as carbon dioxide increases, a larger fraction of incident solar radiation is trapped, and the earth's mean temperature will increase.[5] Carbon dioxide is an absorbing molecule for heat, and the atmosphere is rarely, if ever, completely dry. Attributes of these gases that pose threats can benefit the environment through their heat-absorbing characteristics, aiding human activities that are essential for control and utilization purposes, such as energy generation, environmental protection, and chemical conversion.

The fact is that these gases subscribe to fundamental principles of fluid mechanics, i.e., continuity equation (mass conservation), momentum principle (momentum conservation), and the energy equation (energy conservation).[6] They remain and act under forces acting on them. The forces target specific properties, which subsequently influence behavior. Tracking the behavioral characteristics will highlight trajectories for applications while providing solution(s) where needed.[7]

2. Discussion

Air Composition: The composition of air references different components present in the earth's atmosphere. The air we breathe is mainly made up of nitrogen (78%) and oxygen (21%), crucial for supporting life on earth. Other gases, including carbon dioxide, argon, and water vapor, are also present in smaller amounts yet have a major impact on the atmosphere i.e., composition and utility.[8]It is essential to monitor air composition as we comprehend its impact on human activities and environment while implementing measures aimed at improving air quality and safeguarding public health. The molar composition of air gases encompassing both moist and dry air showcasing their ability to operate within other media and contribute to air composition, is detailed in **Table 1**.

Table 1. Components of Dry Air Composition (Relative Molar Mass) [9]

Components in dry air		Volume ratio = Molar ratio compared to dry air		Molar mass	Molar mass in air	
Name	Formula	[mol/mol $_{air}$]	[vol%]	[g/mol]	[g/mol $_{air}$]	[wt%]
Nitrogen	N_2	0.78084	78.084	28.013	21.872266	75.511
Oxygen	O_2	0.20946	20.946	31.999	6.701942	23.14
Argon	Ar	0.00934	0.934	39.948	0.373025	1.29
Carbon dioxide	CO_2	0.000412	0.0412	44.010	0.018132	0.063
Neon	Ne	0.00001818	0.001818	20.180	0.000367	0.0013
Helium	He	0.00000524	0.000524	4.003	0.000021	0.00007
Methane	CH_4	0.00000179	0.000179	16.042	0.000029	0.00010
Krypton	Kr	0.0000010	0.0001	83.798	0.000084	0.00029
Hydrogen	H_2	0.0000005	0.00005	2.016	0.000001	0.000003
Xenon	Xe	0.00000009	0.000009	131.293	0.000012	0.00004
				Average molar mass of air	**28.9647**	

Thermophysical Properties: The transport properties of gases are underscored by their thermodynamic potential that results in the behavior of gases, reflecting their thermophysical properties through which optimization is possible for control and utilization. Cagran and Pottlacher defined thermophysical properties as a selection of mechanical, electrical, optical, and thermal material properties of metals and alloys (and their temperature dependencies) that are relevant to industrial, scientific, and metallurgical applications, and this covers a wide range of different material properties obtained by numerous different measurement techniques.[10] This definition reflects the applicability of the properties dependent on temperature. In the case of atmospheric gases, their applicability extends beyond the atmosphere. Thermophysical properties of gases control climatic effects via temperature variations or thermal curves.[11] It is important to mention that temperature is a parameter that dictates the behavior of these gases. In the case of energy generation, temperature can affect gas volume in a closed system impacting energy concentration and momentum. It sets the tone for environmental control via density and buoyancy affecting mixing and distribution in the atmosphere. Reaction rates, common to chemists, are massively influenced by a direct proportion similar to the aforementioned. **Table 2** is a representation of behavioral properties crucial for energy generation, environmental protection, and chemical conversion Under standard pressure and temperature, initiating the baseline for further discussion.

Table 2. Thermophysical Properties of Gases at Standard Pressure and Temperature

Properties	N_2	O_2	Ar	CO_2
Density (kg/m³)	1.25	1.43	1.78	1.98
Viscosity ($\times 10^{-5}$ Pa·s)	1.78	2.08	2.22	1.53
Specific Heat (J/kg·K)	1040	918	520	837
Thermal Conductivity (W/kg·K)	0.024	0.026	0.018	0.014
Diffusion Coefficient ($\times 10^{-4}$ m²/s)	0.18	0.17	0.15	0.13

Diffusive Potential: The diffusion coefficient explains the gasses' spreading rate, as shown in **Table 2** and **Figure 1**. However, the diffusion coefficient principle effect, when applied to these gases, tends to decrease as concentration increases and vice versa.[12, 13] At greater heights, diffusion becomes the principal transport process, and the lighter gases become relatively more abundant. Lower density gases' diffusion coefficient decreases due to higher molecular collisions and smaller mean free paths between them.[14-16] The diffusion of atmospheric gases shapes the atmosphere's composition. Factors such as temperature and pressure influence diffusion coefficient, impacting the mixing and distribution of gases. These factors provide valuable insights into the behavior and interaction of atmospheric gases, shaping our environment. At high temperatures, gas molecules gain more kinetic energy and diffuse faster.[17, 18] Increasing movements (high kinetic energy) lead to more frequent collisions between gas molecules and a faster diffusion rate. Conversely, lower temperatures result in slower diffusion rates as gas molecules move slower and have less energy to spread out and mix with other gases. Higher pressure environments tend to have a greater concentration of gases, leading to faster diffusion rates as gas molecules move from high-pressure areas to low-pressure areas; hence, gases spread out more rapidly at higher altitudes where pressures are lower, tolerating a more even distribution of gases in the atmosphere. [19, 20]

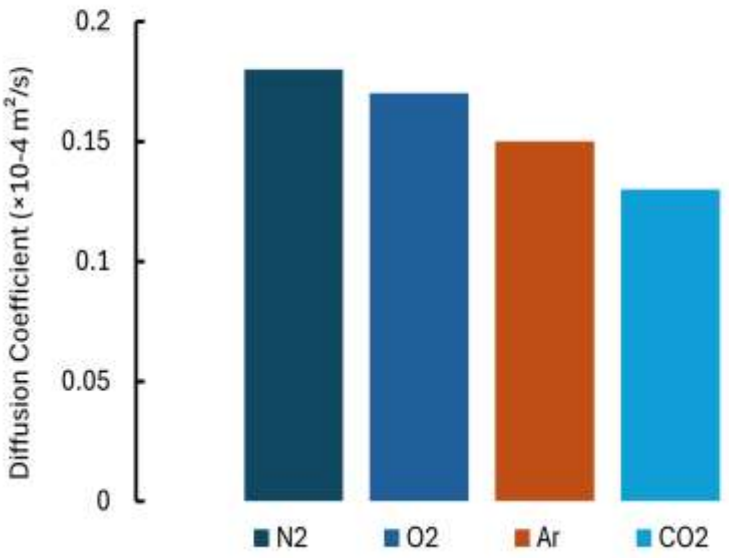

Figure 1 Diffusion Coefficient of Atmospheric Gases (N_2, O_2, Ar, CO_2)

Thermal Conductivity: Materials rely on composition, volume, and, most importantly, temperature as determinants of thermal conductivity. Similar to diffusion coefficient, heat spread can be calculated via heat transfer coefficient. Oxygen (O_2) has the maximum thermal conductivity among the set of gases, as shown in **Table 2** and **Figure 1**. It is no surprise that O_2 is a fire agent. Generally, gases have low thermal conductivity due to low density. Understanding the thermal conductivity of these gases is essential for applications; therefore, engineering applications that prioritize thermal conductivity will favor O_2 the most as the gas with the maximum thermal conductivity from the set of gases. For system optimization and thermodynamic processes, researchers highly consider thermal conductivity. The advancements in research on the thermal conductivity of gases have led to the development of new materials and technologies that utilize gases for efficient heat transfer.[21]

Figure 2 Thermal Conductivity of Atmospheric Gases (N_2, O_2, Ar, CO_2)

Specific Heat: The heating potential of a system rests on the specific heat. The results in **Table 2** and **Figure 3** show that nitrogen gas (N_2) will require the most energy to heat up, resulting in slower temperature changes. The specific heat of the gases also affects their efficiency when utilized in engineering systems. In heat exchangers, gases with high specific heat values are more effective at transferring heat from one fluid to another, leading to more efficient heat transfer. Systems optimization can be achieved by manipulating specific heat values to design more efficient and effective systems for various applications. It is important to note that different gases have different implications on the behavior of systems.[22]

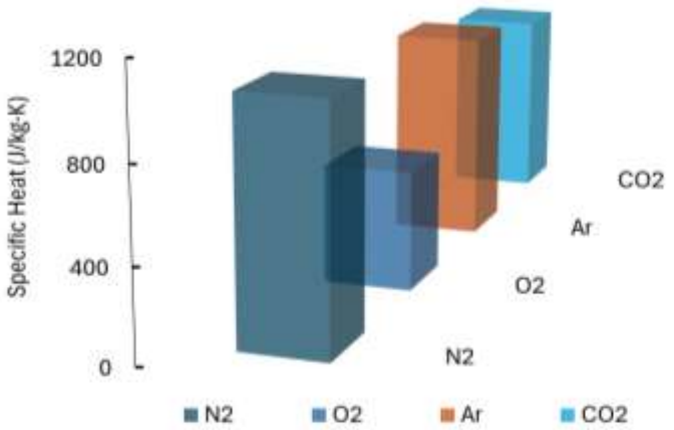

Figure 3 Specific Heat of Atmospheric Gases (N_2, O_2, Ar, CO_2)

Viscosity: Flowrates, pressure drops, heat exchangers, etc., are highly considered in assessing a fluid's viscosity when designing systems to ensure optimal performance and energy efficiency. Gas viscosity causes energy loss. The viscosities shown in **Table 2** and **Figure 4** indicate that argon (Ar) has the maximum viscosity succeeded by O_2, Ar, N_2, and CO_2. Coupling other properties, applications can be assessed and harnessed. Cognizant of Ar limitations, its viscous potential cannot be ignored, especially when requirements for applications and/or utility are established.

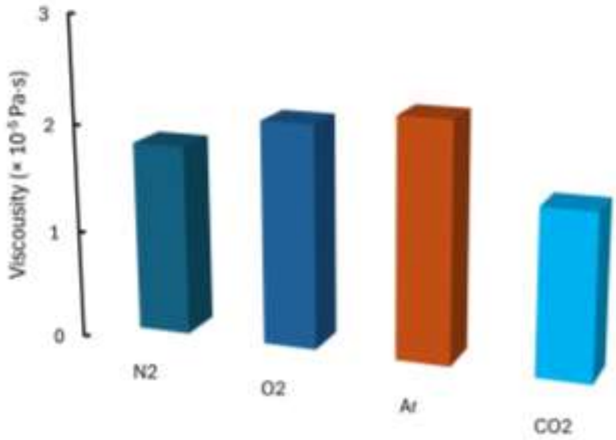

Figure 4 Viscosity of Atmospheric Gases (N_2, O_2, Ar, CO_2)

Density: The flow behavior of gases in transport media is massively influenced by their density. Engineers use the concept of density to analyze and predict flow attributes of gases in various engineering systems, which aids the design of efficient and effective systems for moving gases from one location to another.[23] The density of the air-fuel mixture affects the combustion process (essential for energy generation and chemical conversion) by influencing the amount of fuel that can be burnt and the energy released during combustion.[24, 25] Engineers must carefully control the density of the air-fuel mixture to ensure optimal combustion and maximum efficiency in combustion engines. In refrigeration systems, another important engineering application of gas density, the density of the refrigerant gas, impacts the efficiency of the system and its ability to remove heat from a space. The maximum diffusion coefficient is N_2, followed by O_2, Ar, and CO_2, and the results are shown in **Figure 1**. Density is the opposite of this pattern, with N_2 being the lowest density and CO_2 the highest, and the results are shown in **Figure 5**.

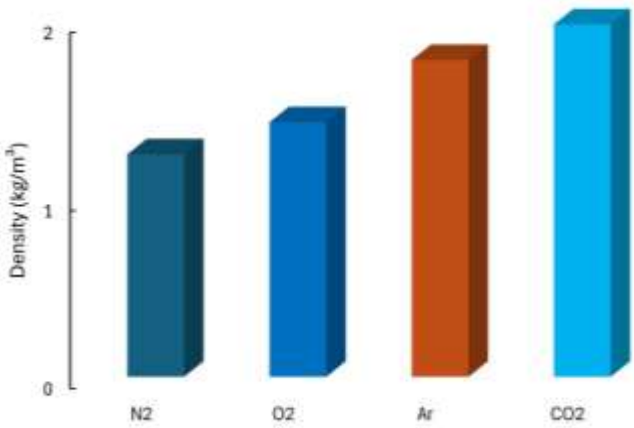

Figure 5 Density of Atmospheric Gases (N_2, O_2, Ar, CO_2)

3. Gases (N_2, O_2, Ar, CO_2) Utilization (Energy Generation, Environmental Protection, Chemical Conversion):

Energy Generation

Energy generation encompasses the combustion process through which natural gases in the atmosphere can be combusted to produce energy and reduce emissions into the atmosphere. The combustion process releases thermal energy, which is essential for mechanical use, and carbon emissions can be reduced with fuel cells in an electrochemical process to produce electricity, thus establishing a major condition for gas utilization, a major solution in today's climate challenges.[26]

The impacts of energy systems performance and optimization of energy output are reliant on the efficiency of energy generation processes, such as power generation and combustion, which are influenced by viscosity. Gas flow in turbines is affected by viscosity, gas compression and storage, heat exchangers, cooling systems, gas transportation, and gasification processes. Lower viscosity enhances energy generation, while higher viscosity reduces gas efficiency. This indicates that among the four atmospheric gases mentioned, CO_2 is the most applicable for energy generation in terms of viscosity.[27]

Obviously, gases with high thermal conductivity transfer heat more easily, resulting in higher efficiency, while gases with low thermal conductivity may require more energy input and lead to decreased efficiency.[28] The study and optimization of gas thermal conductivity in energy generation processes is crucial for maximizing efficiency. Selecting gases with high thermal conductivity and designing systems for efficient heat transfer optimizes energy generation processes, generating more electricity with less fuel input. As we pursue clean and sustainable energy sources, improving gas thermal conductivity will be key to achieving greater efficiency and reducing environmental impact.[29, 30]

Gas specific heat is generated from gases depending on pressure, temperature, and molecular structure. The specific heat of gases is essential for efficiently generating energy from sources, especially natural gas. When gases undergo combustion to generate energy, their specific heat plays a vital role. During combustion, fuel is mixed with O_2 and ignited, producing heat energy in the form of thermal energy. This thermal energy is converted into mechanical energy through steam turbines or internal combustion engines.[31] The heat of the combustion gases determines how efficiently this energy conversion occurs, as the gases must be heated to a certain temperature to release their energy potential. By understanding the specific heat of gases and how it affects energy generation processes, engineers and researchers can optimize the design and operation of these facilities to maximize energy output while minimizing waste and emissions. Gas specific heat and energy generation are interconnected concepts crucial in producing and utilizing gas energy.[32, 33]

Gas density is a fundamental factor in energy generation that directly impacts the efficiency and sustainability of power production. Power plants can improve their overall performance and reduce their environmental footprint by optimizing gas density in combustion processes. Furthermore, understanding the relationship between gas density and energy generation is pivotal for developing more efficient methods for converting renewable resources into usable power. With continued research and innovation in this field, we can enhance energy generation efficiency and reliability while minimizing environmental impact, and more effective methods for converting renewable resources into usable power by understanding the relationship between gas density and energy generation, allowing the design and construction of advanced technologies, such as gas turbines or fuel cells, that can harness the energy potential of gases with varying densities.[34]

Environmental Protection

Carbon Capture and Storage (CCS), Air Quality Management (AQM), and Greenhouse Gas Mitigation (GGM) through which gases such as CO_2 can be captured during combustion processes, utilizing the properties of atmospheric gases essential for pollution control. Monitoring the concentrations of gases like Nitrogen Oxide (NO_x)and Sulfur Oxides (SO_x) helps enforce regulations to protect air quality, reducing the emission of harmful gases and generating renewable energy.[35, 36]

The viscosity of atmospheric gases is important for research involving environmental protection, providing insights into transport and fate of environmental pollutants.[37] Resistance to gas flow and its effect(s) on pollutants dispersement in the atmosphere is measured by gas viscosity. For example, highly viscous gases linger in the air longer than less viscous gases. This causes enhanced air pollution and negative health effects. The effectiveness of various environmental protection measures is also affected by the viscosity of atmospheric gases.[38] A better understanding of gas viscosity aids the efforts of environmentalists in implementing emission control strategies and regulations. Researchers can predict the spread of pollutants and their interaction with the atmosphere by modeling the behavior of different gases with varying viscosities. This is important for developing sustainable solutions to environmental challenges in the future.[39]

Optimizing gas thermal conductivity helps reduce harmful emissions and improves energy transportation efficiency, contributing to environmental protection efforts. It is key in designing catalytic converters for vehicle exhaust systems and natural gas pipeline operations including energy efficiency and pollution control.[40] Leveraging gas thermal conductivity promotes sustainable practices and minimizes environmental impact by reducing energy consumption, minimizing emissions, and preserving natural resources. As we combat the challenges of climate change and environmental degradation, the role of gas thermal conductivity in promoting sustainable practices and protecting the planet will only become more and more significant.[41]

Gases with higher specific heat, such as water vapor and carbon dioxide, can contribute to greenhouse effect, increasing global temperatures and various climate-related disasters. Understanding the heat of atmospheric gases can help develop alternative energy sources and reduce greenhouse gas emissions. Specific heat of atmospheric gases is a significant factor in regulating the planet's temperature and climate. It is imperative to prioritize research and innovation in this field to secure our planet's stable and healthy future. [42, 43]

High gas density can lead to increased pollution being trapped near the Earth's surface, resulting in poor air quality and adversely affecting human and animal health and the environment. The concentration of greenhouse gases and pollutants is highly influenced by gas densities. Variations in density affect the dispersion of pollutants; lower density can allow for greater diffusion, potentially leading to wider distribution of harmful substances. Reducing the spread and emission of pollutants while promoting clean energy sources promoting renewable energy, we can effectively combat air pollution and strive toward a cleaner environment.[44, 45]

Chemical Conversion

Chemical conversions such as photochemical reactions, catalysis, and synthesis are assurances of utilization processes of atmospheric gases. Reactive chemicals essential for industrial applications or other valuable applications can provide valuable energy sources.[46, 47] Materials are transformed into usable energy while minimizing harmful environmental impacts via chemical conversion, which aids processes such as carbon capture and storage, biofuel production, and renewable energy technologies for a more sustainable energy future. These advancements not only provide cleaner and more efficient energy sources but also contribute to environmental protection.[48, 49]

Viscosity affects chemical conversion by impacting mass transfer rate of reactant molecules. High viscosity levels can hinder reactant molecules' movement by slowing reaction rate and causing a major challenge in reactions and industrial applications. The diffusion of reactant molecules to the reaction sites can be impeded, leading to lower conversion rates. [50, 51] Additionally, the viscosity of atmospheric gases can influence the mixing and distribution of reactants within the reactor, further impacting conversion efficiency. High viscosity can lead to regions of low turbulence and poor mixing, resulting in uneven conversion and reduced yields of desired products. Therefore, understanding and controlling gas viscosity (optimizing operating conditions, such as temperature and pressure, to decrease gas viscosity and enhance mass transfer rate) is essential for optimizing chemical conversion processes in industrial settings. By carefully monitoring and adjusting operating conditions to minimize viscosity, engineers can enhance mass transfer rates, improve mixing, and ultimately boost the efficiency and productivity of chemical reactions. This knowledge can inform the design and operation of industrial processes, leading to more sustainable and cost-effective production methods.[52]

Thermal conductivity is a basic thermal component that has a massive influence on gas chemical reactions and the efficiency of expected outcomes. It is a critical parameter in the design and operation of chemical reactors impacting reaction kinetics, heat transfer, and gas mixtures. The conversion of gases with high thermal conductivity to those with low thermal conductivity can potentially mitigate the effects of global warming by reducing their ability to trap heat in the atmosphere. This process also has the potential to enhance energy efficiency, reduce energy consumption, and contribute to sustainable energy practices and environmental conservation efforts. Continued research and development in this field are significant in harnessing its full potential and positively impacting the environment and society.[53]

The specific heat of gases and their chemical conversion are factors essential in shaping our environment. Atmospheric gas-specific heat levels measure its ability to cause climate crisis, yet an asset in chemical conversion for industrial applications. Among the set of gases, as shown **Table 2** and **Figure 3** Nitrogen gas stands out as the maximum temperature-altering potential. Overall, the specific heat influences the energy dynamics of chemical conversions, influencing reaction rates, thermal stability, and conversion efficiency.

Rates of chemical reactions, diffusion of gases, and the formation of key atmospheric components such as ozone layers are highly affected by gas density. Predicting and mitigating the effects of air pollution and climate change will require a deep understanding of these relationships. Amidst a highly dense atmosphere, gas molecules are more likely to collide, leading to frequent chemical reactions. The effect of gas density on the diffusion of gases in the atmosphere cannot be overly emphasized. The chemical conversion of gases in the atmosphere is crucial for maintaining the Earth's atmospheric composition and climate. For instance, the conversion of nitrogen oxides and volatile organic compounds in the atmosphere plays a key role in forming ground-level ozone, a major component of smog. The density of these gases determines the rates at which they react and form ozone, impacting air quality and human health.[55, 56] The chemical conversion of CO_2 regarding application in industrial processes and its effect on the ozone layer towers the rest of the gases in the data set, as shown in **Table 2** and **Figure 5**.

4. Conclusion And Common Applications

The leveraging of atmospheric gases (N_2, O_2, Ar, CO_2) thermophysical properties can enhance energy generation and environmental protection and drive chemical processes; all reputable media for restoring air quality and aiding livelihood. In addition to reducing carbon emissions, proper and efficient utilization is just as important in providing climate solutions. The featured gases in this paper and their interrelationships as atmospheric cohabitants can be exploited for other applications. Before delving into deep innovative research involving atmospheric gases, prevailing conditions surrounding fundamental properties, including thermophysical properties, should be assessed and deemed applicable.

Table 3 Common N_2, O_2, Ar, and CO_2 Applications

Atmospheric Gas	Applications	Details
Nitrogen (N_2)	Industrial Applications	Provides inert conditions to prevent unwanted reactions
	Cryogenics	Employed as refrigerant
	Food Preservation	Used in packaging, replacing oxygen to increase life span of perishable products
	Pharmaceuticals	Used for a controlled environment, ex: eradicating oxygen
Oxygen (O_2)	Medical Use	Primarily used in hospitals for patient breathing support and anesthesia
	Resuscitation Equipment	Oxygen tanks and portable units for emergency medical services.

	Industrial Applications	In steel manufacturing, it is essential for the combustion of fuels and the production of high-temperature flames.
	Water Treatment	Used for aerobic bacteria growth in wastewater treatment processes
Argon (Ar)	Welding	Commonly used as a shielding gas in arc welding to protect the weld area from atmospheric contamination
	Lighting	Employed in fluorescent and incandescent light bulbs to improve efficiency and lifespan
	Metal Production	Used in the production of metals like titanium and other reactive metals
	Research Applications	Utilized in various scientific research experiments.
Carbon Dioxide (CO_2)	Beverage Industry	Used for carbonation in beverages
	Respiration	Enhances plant growth through photosynthesis
	Fire Extinguishers	Employed in certain types of fire extinguishers because it displaces oxygen
	Food Preservation	Modified Atmosphere Packing (MAP) to extend the life of food products

Reference

[1] C. Fabian and Y.-H. Ju, "A review on rice bran protein: its properties and extraction methods," *Crit Rev Food Sci Nutr*, vol. 51, no. 9, pp. 816–827, 2011.
[2] F. N. A. Rahim *et al.*, "Comparison of different protein extraction methods of rice bran protein concentrates," 2021. [Online]. Available: https://www.tci-thaijo.org/index.php/APST/index
[3] S. Bedin, K. Zanella, N. Bragagnolo, and O. P. Taranto, "Implication of microwaves on the extraction process of rice bran protein," *Brazilian Journal of Chemical Engineering*, vol. 36, no. 4, pp. 1653–1665, 2019, doi: 10.1590/0104-6632.20190364s20180599.
[4] S. Bernardi, M. P. Corso, I. J. Baraldi, E. Colla, and C. Canan, "Obtaining concentrated rice bran protein by alkaline extraction and stirring-Optimization of conditions," 2018.
[5] F. N. Abd Rahim *et al.*, "The effect of alkaline extraction and drying techniques on the physicochemical, structural properties and functionality of rice bran protein concentrates," *Int J Biol Macromol*, vol. 242, Jul. 2023, doi: 10.1016/j.ijbiomac.2023.124908.
[6] R. Lucena, "Extraction and stirring integrated techniques: Examples and recent advances," Jun. 2012. doi: 10.1007/s00216-012-5826-9.
[7] A. S. Lozano Pérez, J. J. Lozada Castro, and C. A. Guerrero Fajardo, "Application of Microwave Energy to Biomass: A Comprehensive Review of Microwave-Assisted Technologies, Optimization Parameters, and the Strengths and Weaknesses," Jun. 01, 2024, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/jmmp8030121.
[8] M. Kanapathy, M. S. M. Sarip, S. A. Saidi, M. A. Jamlos, and N. I. A. Aris, "Parametric Study on The Rice Bran Protein Extraction Process Using Water as a Solvent," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, vol. 100, no. 1, pp. 165–171, 2022, doi: 10.37934/arfmts.100.1.165171.
[9] F. N. Abd Rahim *et al.*, "Effect of protein concentration, pH, and ionic strength on the adsorption properties of rice bran protein concentrates at the oil-water interface," *Food and Bioproducts Processing*, vol. 147, pp. 162–174, Sep. 2024, doi: 10.1016/j.fbp.2024.06.011.
[10] F. K. S. Lynaa, M. S. Md Sarip, S. A. Saidi, M. A. H. Mohd Nawi, and K.-I. Sotowa, "Preparation of Rice Bran Protein Solutions Using a Water-Based Extraction Process," *Journal of Chemical Engineering of Japan*, vol. 56, no. 1, Dec. 2023, doi: 10.1080/00219592.2023.2205889.
[11] M. Danaei *et al.*, "Impact of particle size and polydispersity index on the clinical applications of lipidic nanocarrier systems," May 18, 2018, *MDPI AG*. doi: 10.3390/pharmaceutics10020057.
[12] Q. Zhou, H. Li, F. Li, B. Zhang, X. Wu, and W. Wu, "Strategy and Mechanism of Rice Bran Protein Emulsion Stability Based on Rancidity-Induced Protein Oxidation: An Ultrasonic Case Study," *Foods*, vol. 11, no. 23, Dec. 2022, doi: 10.3390/foods11233896.
[13] A. B. Nowakowski, W. J. Wobig, and D. H. Petering, "Native SDS-PAGE: High resolution electrophoretic separation of proteins with retention of native properties including bound metal ions," *Metallomics*, vol. 6, no. 5, pp. 1068–1078, 2014, doi: 10.1039/c4mt00033a.
[14] R. H. Van Wyk and E. O. Amonsou, "Physiochemical and functional properties of albumin and globulin from amadumbe (Colocasia esculenta) corms," *Food Science and Technology (Brazil)*, vol. 42, 2022, doi: 10.1590/fst.02621.
[15] S. Gammoh *et al.*, "Functional and Bioactive Properties of Wheat Protein Fractions: Impact of Digestive Enzymes on Antioxidant, α-Amylase, and Angiotensin-Converting Enzyme Inhibition Potential," *Molecules*, vol. 28, no. 16, Aug. 2023, doi: 10.3390/molecules28166012.