

DEVELOPMENT OF A 3D MODEL OF A PROTOTYPE SYSTEM FOR GEOGAS CAPTURE AIMING AT THE PROSPECTION OF LIGHT HYDROCARBONS

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Abstract: The prospection of light hydrocarbons in soils requires efficient systems for geogas capture; however, existing solutions often combine high cost, operational complexity, and low adaptability to variable field conditions. This study develops an innovative prototype to overcome these limitations, grounded in a critical analysis of patents that identified eight essential technical functions such as sealing against atmospheric contamination, clogging protection, and modular active collection. The methodology integrated a review of consolidated technologies (including Soil Gas Probe and Volatile Organic Compound Monitoring) with parametric CAD modeling, resulting in a modular system of six components interconnected by standardized threads. The design prioritizes constructive simplicity, enabling low-cost laboratory manufacturing, portability for remote areas, and adaptability to different depths and soil types. Compatible with analytical techniques such as gas chromatography via coupling with molecular filters, the prototype requires neither permanent infrastructure nor specialized consumables. Prepared for computational simulations of robustness and gas flow, the model ensures functional validation prior to physical prototyping, reducing risks and costs. As an intermediate solution between artisanal methods and complex industrial systems, it offers operational efficiency for small-scale geochemical prospection, with extended applications to environmental monitoring of VOCs and leak detection. It represents a strategic advance for national tools of sustainable exploration, with prospects for integration into in situ sensors and georeferenced mapping platforms.

Keywords: Geogas Capture, Modular Prototype, Hydrocarbon Prospection.

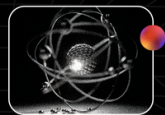
1. Introduction

The patent literature review reveals a vast and diverse range of solutions for interacting with soil gases. At one extreme are highly complex systems for the active extraction of hydrocarbons, which employ technologies such as ultrasonic fracturing of geological formations to release the target compounds (1). However, for geochemical prospection, the focus lies on sampling and analyzing gases already present in the soil.

Within sampling, approaches can be fundamentally divided into two types. The first is advective (active) sampling, in which soil gas is actively drawn by vacuum into the probe, with designs prioritizing the purging of atmospheric

contaminants through valves to ensure sample integrity (2). The second is diffusive (passive) sampling, which seeks to minimize soil disturbance; in these systems, a gas-permeable membrane allows the target compounds to equilibrate with a closed-loop analysis circuit, without the need for vacuum extraction (3).

Detection sensitivity is another point of innovation, with devices focused on pre-concentrating the sample using molecular sieves and adsorbent materials to capture and concentrate light hydrocarbons, which are later thermally desorbed in the laboratory for chromatographic analysis (4). The robustness and field functionality of the probe are also the subject of specific developments, with



optimizations in the mechanical design of the probe tip to prevent clogging of the sampling pathways by soil particles (5). Finally, the integration of the sampler into a broader system is explored in solutions that propose semi-permanent monitoring ports for periodic evaluations (6) or mobile systems that couple sampling to GPS units for real-time mapping of gas concentrations (7).

Despite the diversity of solutions, the combined analysis of these documents reveals a gap in models that integrate constructive simplicity, low cost, operational efficiency for active collection, and adaptability to different field conditions, without relying on complex consumables or permanent installations. In light of this, the present work proposes the development of a three-dimensional model of a prototype system for geogas capture, designed in a CAD (Computer-Aided Design) environment, which may later be manufactured and validated through experimental testing and computational simulations.

2. Methods

The methodology adopted was based on three main stages: analysis of patent documents, selection of technical features, and CAD modeling of the equipment components.

Initially, a search and comparative study of patents related to soil gas capture and geochemical sampling was carried out. This analysis focused on identifying well-established

solutions, their strengths, and limitations, in order to support design decisions better suited to the intended application.

Based on the collected data, a set of priority features for the model was defined, such as structural robustness, ease of assembly and disassembly, feasibility of laboratory manufacturing, and compatibility with sensors and filtration elements. With these premises in mind, six main parts were designed, all modeled in Solid Edge, respecting dimensions and shapes compatible with the technical requirements of the application.

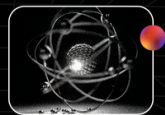
The development of the prototype system for geogas capture was conducted in a three-dimensional modeling environment using Solid Edge software.

Throughout the modeling process, parametric tools and extrusion, revolution, and cutting operations were used to define the geometries. The final assembly was visually validated for fit and functional coherence and prepared for future analysis through structural and flow simulations in Solid Edge, to be evaluated using the NX Nastran environment..

3. Results

From the patent analysis, it was possible to identify the following functions, with their respective characteristics presented in Table 1.

Table 1 – Functions and characteristics of the analyzed patents.



Function	Technical Characteristics	Related Patents
Probe drilling and insertion	Insertion by impact, hydraulic pressure, or manually; conical or retractable tips; use of guide tube (drive tube) to protect the assembly; typical diameter 1–3 cm.	• Volatile Organic Compound Monitoring • Vapor Probe for Soil Gas Vapor Sampler • Soil Gas Probe • Geochemical Soil Sampling for Oil and Gas Exploration
Access point sealing	Sealing with VOC-resistant epoxy or sealants; use of one-way valve or Swedge fitting system; prevents entry of surface air.	• Volatile Organic Compound Monitoring • Soil Gas Probe
Clogging protection	Stainless steel mesh, flexible disks, or “umbrella” to prevent soil particles from blocking inlets; physical protection for collection holes.	• Vapor Probe for Soil Gas Vapor Sampler, • Apparatus and Method for Measuring Soil Gases
Soil gas collection	Intake through gas-permeable membranes, side holes, or slots; conduction via tube to the surface; sampling with pump, vacuum, or carrier gas circulation.	• Apparatus and Method for Measuring Soil Gases • Geochemical Soil Sampling for Oil and Gas Exploration • Soil Gas Probe • Volatile Organic Compound Monitoring
Sample concentration and preservation	Use of collector tubes with molecular sieves; selective adsorption; transport for laboratory analysis.	• Geochemical Soil Sampling for Oil and Gas Exploration
In situ gas analysis	Probe coupled to sensor and datalogger; closed-loop circulation with carrier gas; continuous measurement of concentration and diffusivity.	• Apparatus and Method for Measuring Soil Gases
Purging prior to collection	Connection of an evacuated container to remove residual gases from the probe before collecting the sample.	• Soil Gas Probe, Volatile Organic Compound Monitoring
Periodic monitoring and recording	Scheduled collections; recording in a database; comparison with historical data; risk assessment and mitigation needs	• Volatile Organic Compound Monitoring
Environmental and industrial applications	Hydrocarbon prospection, leak detection in underground tanks, monitoring of VOCs and greenhouse gases.	• All analyzed patents

As a result of the modeling stage, a complete three-dimensional assembly was obtained, composed of six distinct parts that, once assembled, form the prototype system for geogas capture. Each part performs a specific function in the process of capturing, directing, and storing gases extracted from the soil.

Below are the isometric views of the modeled parts:

Figure 1. Equipment assembled with all the parts.

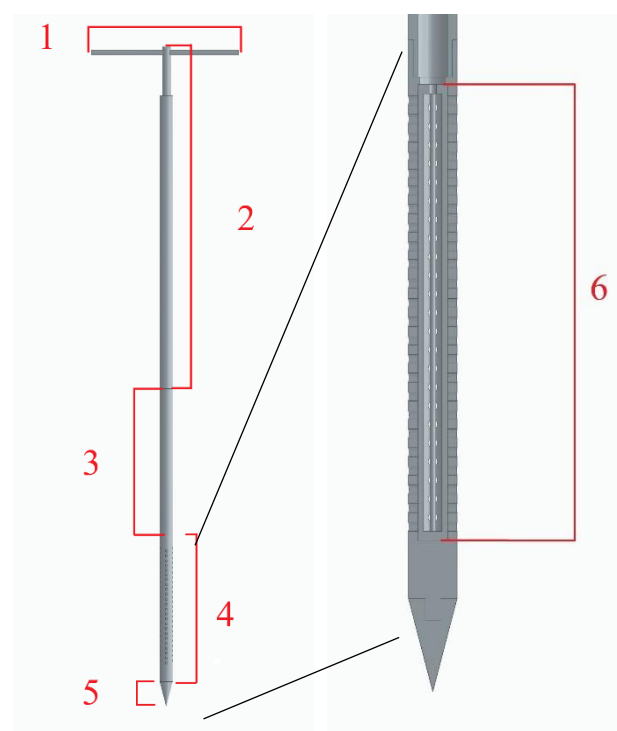
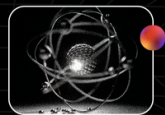


Figure 1 shows all components that make up the prototype, numbered from 1 to 6. Elements 1 and 2 are joined by welding, forming the interface with the operator and remaining positioned externally to the soil. The lower end of element 2 is threaded to element 3, which acts as an extension piece, allowing the equipment's depth



to be increased, and connects to element 4 also by threading.

Element 4 is the central part of the equipment, responsible for direct interaction with the soil. Through multiple holes distributed along its surface, the geogas enters the system's interior. Inside it, element 6 is housed, serving as a support for the dust-proof mesh and the molecular sieve. At the bottom, element 4 is threaded to element 5, which corresponds to the drilling tip. Since it is threaded, this tip can be replaced according to the project's requirements.

4. Discussion

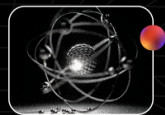
The comparative analysis of the patents indicated a wide variety of solutions for soil gas collection and analysis, ranging from simple manual insertion systems to complex devices integrating sensors and pre-concentration modules. Recurring functions such as probe drilling and insertion, access point sealing, and clogging protection appear in multiple records, reflecting their importance in ensuring sample integrity and process efficiency. Other functions, such as in situ gas analysis and periodic monitoring, highlight automation trends and integration with analytical systems, especially for continuous industrial and environmental applications.

From Table 1, it can be observed that patents such as Volatile Organic Compound Monitoring and Soil Gas Probe prioritize contamination control and sample collection repeatability, while

solutions like Geochemical Soil Sampling for Oil and Gas Exploration and Apparatus and Method for Measuring Soil Gases explore pre-concentration techniques and direct measurements. Despite their robustness and technical efficiency, many of these solutions involve high manufacturing costs, the use of specialized consumables, or the need for permanent installation, which may limit their applicability in small-scale exploratory campaigns or remote regions.

The prototype developed in this work incorporates essential functions identified in the analyzed patents but adapts them to a modular, portable, and low-cost format, prioritizing constructive simplicity and ease of assembly and maintenance. Elements such as the threaded tip (element 5) and the dust-mesh holder (element 6) replicate sealing and filtering principles found in consolidated models but were redesigned for compatibility with laboratory manufacturing and operation in different soil types.

Furthermore, the simplified geometry and use of standardized threads allow the coupling of extensions (element 3) for different sampling depths, meeting the adaptability requirement identified in the patent literature. Compatibility with filters and molecular sieves enables future integration with analysis systems such as gas chromatography, aligning with trends in qualified and quantitative measurements of light hydrocarbons.



Finally, preparing the model for simulations in NX Nastran represents a methodological advantage, allowing prediction of structural and functional performance before physical construction, thereby reducing risks and costs in the prototyping process. Thus, this development positions itself as an intermediate solution between artisanal models and highly specialized systems, offering versatility for applications in geochemical prospecting, environmental monitoring, and exploratory research.

The parts were modeled to allow simple assembly without the need for complex tools. Their geometries were adjusted to ensure sealing and mechanical integrity, enabling subsequent use in experimental gas collection under real field conditions. The model is also ready to be computationally analyzed for structural and performance validation.

From the analysis of existing patents in the field of soil gas capture, it was possible to observe a diversity of technical solutions, varying in terms of constructive complexity, materials used, and integration with analytical systems. However, many of the models found presented limitations related to portability, manufacturing cost, and adaptability to different soil types and sampling depths.

The model developed in this work seeks to address some of these gaps by incorporating a modular approach, composed of parts with simplified and functional geometry. The use of Solid Edge as a modeling tool made it possible to

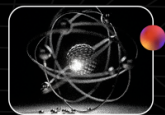
explore different configurations until reaching an optimized set of parts that meet the defined technical requirements, with a focus on practical feasibility.

In addition, the proposal stands out for considering, from its conception, compatibility with analysis systems such as gas chromatography, by allowing the coupling of filters and sensors. Another relevant point is the preparation for future simulations in the NX Nastran environment, which will make it possible to evaluate the structural and functional behavior of the system before its fabrication.

Thus, this work advances toward providing a solid basis for the construction of devices applicable in geochemical prospecting campaigns, particularly aimed at identifying light hydrocarbons in terrestrial environments.

6. Conclusion

The development of the three-dimensional model of a prototype system for geogas capture, presented in this work, was grounded in a detailed review of relevant patents in the field of geochemical sampling. This analysis made it possible to identify essential functions such as drilling and probe insertion, efficient sealing, clogging protection, and active gas collection, as well as features associated with pre-concentration, in situ analysis, and periodic monitoring.



By incorporating these functions in an adapted manner, the prototype stands out for its modularity, constructive simplicity, and portability — aspects rarely explored in consolidated commercial solutions. The use of threaded components, optimized geometries, and compatibility with different soil types provides flexibility for application in exploratory campaigns for light hydrocarbons, without requiring permanent infrastructure or high-cost consumables.

In addition, compatibility with filters and molecular sieves broadens the potential for integration with analytical techniques such as gas chromatography, while preparing the model for simulations in NX Nastran ensures a structural and functional validation stage prior to physical fabrication, minimizing risks and costs.

Thus, the proposed prototype represents a strategic advance in the development of national tools for geochemical prospecting, combining operational efficiency, economic feasibility, and adaptability. Its future application could meet not only exploratory demands in the oil and gas sector, but also environmental monitoring and scientific research in diverse geological contexts

from:

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