Online ISSN: 2249-4596 Print ISSN: 0975-5861 DOI: 10.17406/GJRE

Global Journal

OF RESEARCHES IN ENGINEERING: J

General Engineering

Dispatchable Renewables

Characterization of Saltwater

Highlights

Selecting a Right Pathway

Diagnosis of Parkinson's Disease

Discovering Thoughts; Inventing Future

VOLUME 24 ISSUE 1 VERSION 1.0

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GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J General Engineering

GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J General Engineering

Volume 24 Issue 1 (Ver. 1.0)

Open Association of Research Society

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Offset Typesetting

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Packaging & Continental Dispatching

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GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Dispatchable Renewables: Selecting a Right Pathway

By Alexandre Pavlovski

Abstract- Clean Grid readiness is a major objective of Canada's Clean Grid 2035 efforts and commitment to make all electricity generation in the country carbon net-zero. Making all the sources of electricity in power grids clean would be a tremendous step in Canada's energy transition and low carbon economy growth.

Deploying on a very large scale variable renewables such as wind and solar in Canada requires an extremely significant power dispatchability effort, allowing the country's power grids to maintain their reliability. Dispatchable generation refers to controllable and flexible sources of electricity that can promptly respond to demand at the request of power grid operators. The Clean Grid 2035 commitment assumes that all existing and new power dispatchability sources in Canada backing up variable renewables' operations are clean.

Keywords: carbon net zero, electric federalism, clean grid readiness, variable renewables, dispatchability reserves, hydro power, geothermal power, clean power generation, renewable dispatchable fleet, interchange.

GJRE-J Classification: LCC: TK3105



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Dispatchable Renewables: Selecting a Right Pathway

Alexandre Pavlovski

Abstract- Clean Grid readiness is a major objective of Canada's Clean Grid 2035 efforts and commitment to make all electricity generation in the country carbon net-zero. Making all the sources of electricity in power grids clean would be a tremendous step in Canada's energy transition and low carbon economy growth.

Deploying on a very large scale variable renewables such as wind and solar in Canada requires an extremely significant power dispatchability effort, allowing the country's power grids to maintain their reliability. Dispatchable generation refers to controllable and flexible sources of electricity that can promptly respond to demand at the request of power grid operators. The Clean Grid 2035 commitment assumes that all existing and new power dispatchability sources in Canada backing up variable renewables' operations are clean.

Choosing to have the renewable segment of clean dispatchability sources lead in Canada's Clean Grid efforts and creating renewable dispatchable fleets - the clean power generation fleets that will make all variable renewables in the country dispatchable. Canada's extremely strong reservoirbased dispatchable hydro power generation in Newfoundland and Labrador. Quebec and Manitoba can participate in these fleets to back up variable renewables' growth in the country. Canada's unique geothermal power generation in the Pacific Rim, including the regions of northeastern British Columbia and southern Yukon, northern Alberta and southern Northwest Territories, constitutes very high potential for highly dispatchable electricity generation to participate in renewable dispatchable fleets.

The proposed approach to using hydropower as a variable dispatchability reserve for Eastern Canada and hydropower and geothermal power combining as dispatchability reserves for Western Canada will make variable renewables dispatchable, upgrading all power grids in Canada to 100% Clean Grid readiness by 2035 and maintaining this Clean Grid commitment in 2050 and beyond. Using dispatchable hydropower and geothermal power together with wind and solar power in Renewable Dispatchable Fleets would make all renewable capacity dispatchable, establishing leading clean dispatchability practices in North America.

To agree on Renewable Dispatchable Fleets deployment and existing Renewable Dispatchability Reserves commitments from the provinces owning and operating large scale reservoir-based hydro power plants, Canada's "electric federalism" concept and approach should be demonstrated efficiently and promptly.

Keywords: carbon net zero, electric federalism, clean grid readiness, variable renewables, dispatchability reserves, hydro power, geothermal power, clean power generation, renewable dispatchable fleet, interchange.

Graphic Abstract



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I. INTRODUCTION

a) A Growing, Clean Economy

anada is currently competing globally for its share in a low carbon economy [1]. According to the Government of Canada vision, the country must capitalize on Canada's competitive advantages, including critical resources needed by the world, and the country's skilled and diverse workforce. Canada is bringing solutions for and "business bridges" between highest-quality manufacturing at home and exporting leading products and services globally.

To successfully grow the economy while averting the worst impacts of climate change, the Government of Canada is committed to meeting an ambitious climate target of 40-45% emissions reductions by 2030 and achieving net-zero emissions (where our economy either emits no greenhouse gas emissions or offsets its emissions) by 2050 [2].

b) Total Electrification Targets and Steps

Electricity is becoming the key fuel for low carbon economy activities in Canada. Today the country is committed to total electrification. By fully decarbonizing Canada's electricity grids by 2035, our country is enabling the rest of the economy to electrify by 2050 [3].

According to the 2023 federal budget, Canada's electricity demand is expected to double by 2050. To meet this increased demand with a sustainable, secure, and affordable grid, the country's electricity capacity must increase by 2.2 to 3.4 times compared to current levels. To achieve both objectives, the Government of Canada is committed to ensuring that an emissions-free grid ("Clean Grid") target has been achieved by 2035 [4]. These commitments expect phaseout of coal generation in 2030, clean grid deployment, with last sales of new internal combustion engine vehicles in 2035, and net-zero total emissions in 2050 [2].

c) Energy Transition means Dispatchable Renewables

Ensuring the increasing penetration of renewable power into the energy supply mix, towards total electrification, is very often referred to as an "energy transition" [5]. Moving from fossil fuel-based to clean electricity-based electricity sources and scaling the growth of clean electricity changed the role of renewables from historically "secondary" to today's "primary" in building Canada's low carbon economy.

This means that all clean electricity generation fleets on the grid, including variable renewables such as wind or solar, should be made dispatchable by keeping necessary clean dispatchability reserves.

Dispatchable renewables in Canada are presented by large reservoir-based hydro power strongly established in the country. Hydro power generating stations have been for many years contributing to electricity use at home as well as to exporting electricity as a valuable product. This includes hydro power in Newfoundland and Labrador, Quebec, Manitoba, and British Columbia [6-10].

opportunities Dispatchable renewables in Canada are also presented by geothermal resources. Enhanced Geothermal Systems for power generation based on deep geothermal resources can provide power generation as well as clean dispatchability reserves. Geothermal power is economically attractive in energy transition process [11-14] that is seen as a longer-term objective in Canada. The high capacity factor of geothermal power makes it particularly attractive as a renewable resource for highly dispatchable electricity generation. Geothermal resources with high (> 150°C) temperatures allow very high potential for electrical generation in regions of northeastern and southern Yukon, northern Alberta, and southern Northwest Territories.

Using hydro and geothermal power sources and clean dispatchability resources for variable renewables allows for integrating dispatchable renewable fleets to address the Clean Grid goals in Canada in mid- and long-term.

d) Realizing Electric Federalism

Achieving net zero goals in Canada through energy transition requires an approach often referred to as electric federalism [15]. In the Canadian federation, electric federalism presents coherent policy actions from federal, provincial, and territorial governments focused on upgrading and aligning all electricity systems in Canada to meet net zero in a timely manner.

Currently, electricity In Canada is provincially regulated, and system planning still occurs in silos, leaving no overarching entity to enact policies and changes that ensure these benefits are realized. Instead, it is voluntary on the part of provinces and territories.

The electric federalism approach is seen as a core basis for moving forward in integrating renewable dispatchable fleets through regional integration and related close collaboration. Interregional integration through strong interties will improve economic efficiency due to the technical benefits of larger, integrated power systems.

Based on the understanding of electric federalism in 2024, policy interventions from federal, provincial, and territorial governments are expected to upgrade and transform electricity systems in Canada, allowing for growing renewable dispatchable fleets. This includes considerable policy leadership from the provinces, since they control many of the key policy levers, and an important enabling and accelerating role played by the federal government [15].

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e) Investment in Dispatchable Renewables: Calling for Actions

Completing Renewable Dispatchable Fleets integration efforts and achieving Clean Grid goals and objectives within 2025-2035 time frame requires prompt and efficient investment decisions at federal and provincial levels.

The federal government can complement its policy efforts related to Renewable Dispatchable Fleets —including support for integration in the electricity sector —with financial support for clean dispatchable reserves deployment that incentivize provincial and territorial governments to exercise their policy tools. In return for coordinated provincial and territorial policy action focused on investments in Renewable Dispatchable Fleets, the federal government could offer more stable long-term funding for provincial and territorial electricity transformations [15].

As indicated in Canada's 2023 Budget, "...Given the long lead times and high upfront costs for electricity generation and transmission projects—and with our allies and partners set to invest heavily in preparing their own electrical grids for the future— Canada needs to move quickly to avoid the consequences of underinvestment" [1].

The Canada Infrastructure Bank is seen as an active partner in supporting these efforts by making investments in renewable energy, energy storage, and transmission projects. These investments may position the Canada Infrastructure Bank as the government's primary financing tool for supporting clean electricity generation, transmission, and storage projects, including for major Renewable Dispatchable Fleet Integration projects in Canada.

Overall, based on the electric federalism rooted in negotiated agreements of the federal government with provinces, as well as historical and current experiences of the provinces with power transmissions, intraprovincial interties and international interconnections, Renewable Dispatchable Fleets in Canada would provide a unique solution for the country to achieve its net zero goals and commitments "in a way that makes sense in the Canadian federation" [15].

This paper is focused on efficient and effective ways of growing Renewable Dispatchable Fleets in Canada's energy transition. It describes proposed changes in clean dispatchability reserves meeting clean generation mix and "Clean Grid 2035" objectives and commitments. Specifically, the following issues are discussed:

- Available dispatchability reserves for variable renewables planned in each of the provinces and territories by 2035;
- Review of existing Clean Dispatchability Reserves in each of the provinces;

- Review of new Renewable Dispatchable assets for each of the provinces using the experience with their existing renewable assets and geo-economical [16] resources;
- Review of an electric federalism [15] approach to potential shares of Clean Dispatchability Reserves considered by the provinces to meet the Canadian "Clean Grid 2035" commitment.

II. MATERIALS AND METHODS

a) Approaching Dispatchable Renewables

i. Clean Grid Readiness Commitment

A starting point for approaching dispatchable renewables vision in Canada is closely related to clean grid as a major goal. Indeed, among the ten provinces that have been using 99.8% of electricity in Canada, seven provinces, for different geo-economic reasons, historically committed to clean electricity generation, mostly based on hydro or/and uranium (even Ontario, the second largest electricity generation-wise in Canada, has only less than 7% of electricity from natural gas in 2022). Only three provinces (Alberta. Saskatchewan, and Nova Scotia) have had their electricity generation heavily based on fossil fuels and are currently addressing a unique task of deploying very large scale renewable fleets within a decade to contribute to Canada's Clean Grid 2035 commitment [17].

Table 1.1 below shows "clean grid" readiness targets (in percent) for each of the Canadian provinces. These targets indicate electricity generation projections of the Canada Energy Regulator (CER). Most recent data provided by CER is analysed in its Energy Future report of 2023 (further-EF2023) [18] presenting first long-term outlook. The report presents its key findings in Current Measures, Canada NetZero, and Global NetZero scenarios (Global NetZero scenario is not discussed in this paper).

Electricity Generation:	20	30	2035		
Clean Grid Readiness, %	NetZero	Current	NetZero	Current	
Alberta	36.6%	17.9%	95.1%	20.6%	
British Columbia	81.0%	84.8%	96.4%	85.8%	
Manitoba	99.8%	99.8%	99.9%	98.7%	
New Brunswick	96.7%	98.0%	99.1%	99.1%	
Newfoundland and Labrador	100%	100%	100%	100%	
Northwest Territories	85.3%	95.1%	94.1%	96.7%	
Nova Scotia	92.4%	35.2%	99.7%	39.8%	
Nunavut	6.0%	6.1%	35.5%	39.4%	
Ontario	87.3%	90.9%	97.6%	90.8%	
Prince Edward Island	97.7%	98.3%	99.8%	99.6%	
Quebec	99.2%	98.7%	99.3%	96.2%	
Saskatchewan	52.2%	52.3%	98.3%	61.1%	
Yukon	50.2%	54.6%	69.8%	74.2%	

Shaded in Table 1.1 are the provinces of Alberta, Saskatchewan, and Nova Scotia which because of historical business development reasons require support in Clean Grid Readiness.

According for EF2023, in Canada NetZero scenario variable renewables Alberta, Saskatchewan and Nova Scotia are expected to deploy 50% of wind power generation and 63.7% of solar power generation in Canada. While, as a leading nation globally, Canada has committed to the clean electricity grid concept supporting a low-carbon economy and adaptation to climate change, thoughtful and strategic business and community approaches have to be supported in Alberta, Saskatchewan, and Nova Scotia to meet the federally proposed timelines.

These approaches have keep all to clean/renewable sources dispatchable, and to strengthen electricity export opportunities both in Eastern and Western Canada. Today these approaches clearly exist and are technically doable within the "clean arid 2035" time frame.

In Eastern Canada they are presented by largescale onshore and/or offshore wind power in the Canadian part of the Atlantic Rim (e.g., off Sable Island and other related areas) that can be supported by hydro power from Newfoundland and Labrador (so called "Atlantic Axis" of power transmission).

In Western Canada they are also presented by large-scale deep geothermal power on the border of Alberta, British Columbia and Yukon in the Canadian part of the Pacific Rim overlapping the Pacific Ring of Fire. This major geothermal opportunity may be called the "Pacific Axis" of power transmission. The opportunity will not only address electricity needs in the regions, but it can also provide power dispatchability reserves much beyond the target provinces in Western Canada. Technologies for enhanced geothermal systems have been developed and tested in Alberta and invested in globally (see [19,20]. It is expected that negotiations of the federal government with Alberta and Saskatchewan will bring this opportunity to the forefront of public policies and decision making at the federal and provincial levels.

While the EF2023 report reviewed five "What If" cases (such as wide-scale adoption of hydrogen, small modular reactor, direct air capture and carbon capture, utilization, and storage technologies maturity, and higher peak electricity demand due to electric vehicles charging) that may address uncertainties on the pathway to net-zero and possible changes in key assumptions in the report, it did not look into the ways of supporting the growth of variable renewables by available dispatchability reserves planned in each of the provinces and territories by 2035, the role of existing Clean Dispatchability Reserves in each of the provinces, including Renewable Dispatchability Reserves, and opportunities with Enhanced Geothermal systems and technologies based on Canadian geo-economical resources [16].

Although the future of energy in Canada is broader than the economic and technical factors driving the projections in EF2023, and many of these factors are beyond the scope of EF2023 analysis, some of these factors require critical attention and should be very promptly addressed as they touch very sensitive decisions of Canadian provinces and realities of electric federalism in Canada.

The following sections of this paper are dedicated to the two related factors: dispatchability of variable renewables, and enhanced geothermal systems as a renewable dispatchable asset available for deployment and critically needed in Canada.

ii. Data Sources and Assumptions

a. Data Sources

For this publication the Author used the data on electricity demand, generation, capacity, interchange, and other related data for provinces in Canada provided publicly by the Canada Energy Regulator's (CER) [21]. Projections to 2050 were presented by CER in the "Canada's Energy Future 2023" (further - EF2023) report [18]. The data as of February 2024 was used.

The period for Energy Supply and Demand Projections was limited in this paper to 2023-2035 and focused on the Canadian "Clean Grid 2035" commitment.

The core data tables were limited to Canada NetZero and Current Measures scenarios presented in [18].

The core data tables included:

- End Use Demand (petajoules)
- Electricity Generation by Primary Fuel (GWh)
- Electricity Generation by Technology (GWh)
- Electricity Capacity by Primary Fuel(MW)
- Electricity Capacity by Technology (MW)
- Electricity Interchange (GWh)

Electricity generation technology and its capacity included *fossil fuel* group, such as Carbon Capture, Utilization and Storage (CCUS) technology advancements that capture the greenhouse gas carbon dioxide (CO2) and utilize it or store it safely underground (this includes Coal and Coke, Natural Gas, and Oil), *cleaner fuel* group (Bioenergy, Bioenergy with CCUS,

In Current Measures scenario (table 1.3.1):

Coal with CCUS, Natural Gas with CCUS) and *clean fuel* group of technologies (Hydro, Hydrogen, Onshore Wind, Offshore Wind, Solar (Distributed), Solar (Utility scale), Uranium, Uranium SMR).

The recent CER's EF2023 report [18] does not include geothermal electricity generation, a very powerful clean primary fuel and electricity generation technology with major energy resources in Canada.

b. Assumptions

Only existing and/or ready for deployment cleaner fuel and clean fuel technologies were used for "clean grid 2035" commitment.

Specifically, Cleaner Fuel included:

- Coal with CCUS and Natural Gas with CCUS
- Biomass with CCUS generation (conventional biomass was not included in "clean grid 2035" analysis)

In Clean Fuel the following assumptions were made:

- No tidal and wave generation was used in 2035 or earlier.
- No geothermal generation was used in EF2023 in the 2023-2035 period; in this paper Enhanced Geothermal Systems were proposed to be used starting 2031 after 7 years (2024 to 2030) of development.

iii. Current Vision of Clean Grid Support

Based on the Canada Energy Regulator's vision [18] of expected changes in Alberta, Saskatchewan and Nova Scotia, the situation in these three provinces defining a need for "clean grid" support to achieve the 2035 target is seen as follows:

Table 1.3.1: Electricity demand	generation,	and interchange	in target provinces:	Current Measures
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Current Measures	2025				2030		2035			
Scenario, TWh	Demand	Generation	Interchange	Demand	Generation	Interchange	Demand	Generation	Interchange	
Alberta	83.83	93.01	9.18	92.17	105.74	13.57	100.55	112.39	11.84	
Saskatchewan	27.00	26.60	-0.39	29.41	28.39	-1.01	31.68	30.77	-0.90	
Nova Scotia	11.79	7.81	-3.98	12.92	9.53	-3.38	13.86	10.13	-3.73	

and in Canada NetZero scenario (table 1.3.2):

Table 1.3.2: Electricity demand, generation, and interchange in target provinces: Canada NetZero

Canada Net-Zero	2025				2030		2035			
Scenario, TWh	Demand	Generation	Interchange and Loss	Demand	Generation	Interchange and Loss	Demand	Generation	Interchange and Loss	
Alberta	81.61	90.39	8.77	97.15	106.78	9.63	117.17	128.49	11.32	
Saskatchewan	26.08	25.75	-0.33	30.26	29.76	-0.50	36.41	35.38	-1.03	
Nova Scotia	11.97	7.80	-4.17	13.70	14.10	0.40	15.52	21.66	6.15	

EF2023 data for the 2025 to 2035 period including Electricity Demand, Generation, and Interchange in all Canadian provinces is summarised in Appendix A.

EF2023 electricity generation data by fuel for Alberta, Saskatchewan and Nova Scotia for NetZero and Current Measures scenarios is presented in Appendix B. Based on EF2023 data, the current vision of Canada's Clean Electricity Future presents an approach where clean (Hydro, Onshore Wind, Offshore Wind, Solar (Distributed), Solar (Utility scale), Uranium SMR) and cleaner (e.g., Bioenergy with CCUS, Natural Gas with CCUS) fuels are planned to be used to achieve the "clean grid 2035" target in Alberta, Saskatchewan, and Nova Scotia.

In the NetZero scenario the following technology capacity for clean and cleaner fuels is expected as follows (table 1.3.3):

Alberta, Saskatchewan, and Nova Scotia - Total, MW	2025	2030	2035
Cleaner Fuels, MW	0	2,090	5,587
Cleaner Fuels, %	0%	13%	11%
Clean Fuels, MW	8,749	14,309	45,055
Clean Fuels, %	100%	87%	89%
Total clean/cleaner fuels, MW	8,749	16,399	50,642
Total clean/cleaner fuels, %	100%	100%	100%

Specifically, the total of clean technology capacity in the three provinces presents the major effort in the country in NetZero scenario - see tables 1.3.4 and 1.3.5 below:

Table 1.3.4: Clean and Cleaner Fuel Ca	pacity in Target Provinces
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Canada NetZero Scenario	Alb	erta	Saskatc	hewan	Nova Scotia		
	Deployed	between	Deployed	between	Deployed between		
Technology Capacity, MW	2026-2030	2031-2035	2026-2030	2031-2035	2026-2030	2031-2035	
Solar (Distributed)	279.17	500	80	50	9	2.5	
Solar (Utility scale)	750	11070	32	1354	0	0	
Offshore Wind	0	0	0	0	2000	3000	
Onshore Wind	1560	11440	850	1800	0	0	
Natural Gas with CCUS	2090	2200	0	13.3	0	0	
Bioenergy with CCUS	0	728	0	556	0	0	
Uranium SMR	0	459	0	1070	0	0	

Table 1.3.5: Clean and Cleaner Fuel Capacity Shares

Canada NetZero Scenario	CAN	IADA	Alberta, Saskatchewan, and Nova Scotia TOTAL					
	Deployed between		Deployed	between	Share, % Deployed between			
Technology Capacity, MW	2026-2030	2031-2035	2026-2030	2031-2035	2026-2030	2031-2035		
Solar (Distributed)	1,237	1,329	368	553	30%	42%		
Solar (Utility scale)	1,350	14,862	782	12,424	58%	84%		
Offshore Wind	2,000	3,000	2,000	3,000	100%	100%		
Onshore Wind	5,319	27,046	2,410	13,240	45%	49%		
Natural Gas with CCUS	2,090	2,213	2,090	2,213	100%	100%		
Bioenergy with CCUS	0	1,451	0	1,284	0%	89%		
Uranium SMR	300	13,072	0	1,529	0%	12%		

In the NetZero scenario the clean fuel effort made by Alberta, Saskatchewan, and Nova Scotia in 2035 is led by wind power (20.7 GW, 103.8 TWh) followed by solar power (14.1 GW, 21.6 TWh) and Uranium SMR (1.5 GW, 9.46 TWh).

Table 1.3.5 shows the provinces leadership in deployed capacity in Canada: 49% onshore wind, 100% offshore wind, 84% utility-scale solar.

To address the issues related to these capacities, the review and discussion in this paper is focused on clean fuels only, presenting close to 89% of the potential effort by 2035.

Variable renewables capacity data for Alberta, Saskatchewan and Nova Scotia planned by Canada Energy Regulator for 2030 and 2035 (see tables 1.3.4 and 1.3.5) is used in the following sections to define available dispatchability reserves required and available in these target provinces.

b) Making All Renewables Dispatchable

i. Power Dispatchability Definition and Applications

Dispatchable sources are electricity sources that can be ramped up or down in a relatively short time – from milliseconds (e.g., grid batteries or spinning reserves) to minutes (e.g. natural gas and hydro turbines) and hours (e.g., coal, biomass, or nuclear plants), which is defined by electricity demand (load) and related operating conditions in the power grid [22,23].

Depending on the nature of dispatchable sources, they may be used for grid operations tasks such as load matching and peak matching, as well as supporting so-called "lead-in times" required by large coal or natural gas fueled electricity generators to reach full output.

This functionality of dispatchable sources may be extended to ancillary services that include active power/frequency control and reactive power/voltage control, on various timescales for maintaining grid stability and security [24].

ii. Dispatchability of Renewables Today

Today's general understanding of the dispatchability of renewable power plants divides them into two major groups:

- *Non-dispatchable:* Solar photovoltaic (PV) and wind power plants
- *Dispatchable:* Hydroelectric, biomass, geothermal and ocean thermal energy conversion-based power plants.

For techno-economical reasons related to the temperature of the surface waters in Canada's Maritime Zones [25], ocean thermal energy conversion technology applications [26, 27] are not described in this paper.

Also, for local carbon economy reasons only natural gas-based and biomass power plants enabled with Carbon Capture, Utilization and Storage (CCUS) solutions are further discussed in this paper.

iii. Capacity Value of Variable Renewables for Dispatchability Reserves

When dealing with variable ("non-dispatchable") renewable power sources such as wind or solar PV, grid operators have to keep ready-to-use dispatchable reserves to continuously maintain the balance between electricity generation (supply) and consumption (demand).

The amount of dispatchable reserves needed to be at hand in any utility service area with wind and/or solar power plants addressing the natural intermittency (variability) of these resources to smooth out electricity generation is defined by the Capacity Value of variable generation plants. Capacity Value is the contribution that a plant makes toward the planning reserve margin [28] measuring the amount of generation capacity available to meet expected demand in planning horizon. For variable generation plants it means that a dedicated dispatchable reserves matching these plants will be added to the reserve margin.

When variable (wind or solar) generation is deployed, to ensure resource adequacy [29-32] of an electricity system grid operators determine Capacity Value of variable generation using reliability-based methods such as Effective Load Carrying Capability (ELCC), Equivalent Firm Capacity (EFC) or Equivalent Conventional Power (ECP) [33]. E.g., ELCC of a variable generation plant is defined as the amount by which the system's loads can increase when the plant is added to the electricity system while maintaining the same system reliability of the system. Determined through a set of detailed calculations considering all possible intermittency and/or contingency scenarios for a utility. ELCC defines the required planning reserve that may or may not be available depending on the renewable generation output [34-37].

For growing penetration of wind and solar power in electricity generation, ELCC defines incremental changes in variable generation plants deployment and cumulative changes in variable generation.

An example of wind deployment is presented by Nova Scotia Power Inc. [38]. Adding 355 MW of wind power to 545 MW of wind power existing in the system brought incremental capacity value of 12% for this change and changed cumulative capacity value of wind power in the system from 26% (141.7 MW) at 545 MW level to 19% (171 MW) at 900 MW level. It is important to highlight that while cumulative capacity value of variable generation in terms of physical capacity (MW) is increasing with its penetration in the system, it is also decreasing as the fraction of its nameplate capacity (%).

Using the cumulative capacity value of wind power and solar power in Nova Scotia, Alberta, and Saskatchewan, and in Canada overall, we can define the level of dispatchable reserves to contribute to the planning reserve margins that are required for variable generation deployment towards Clean Grid 2035 targets in both Current Measures and Canada NetZero scenarios presented by EF2023 – see Tables 2.3.1 and 2.3.2 below.

Canada NetZero	Alberta			Sa	Saskatchewan			Nova Scotia		
Scenario, MW	2025	2030	2035	2025	2030	2035	2025	2030	2035	
Total capacity, MW	21,478	25,857	46,914	7,476	8,454	11,891	3,314	5,940	8,130	
Solar (Distributed), MW	220.83	500	1000	20	100	150	1	10	12.5	
Solar (Utility scale), MW	1180	1930	13000	84	116	1470	0.37	0.37	0.37	
Total Solar Power, MW	1,401	2,430	14,000	104	216	1,620	1	10	13	
Grid Penetration Solar, % of total capacity	6.5%	9.4%	29.8%	1.4%	2.6%	13.6%	0.0%	0.2%	0.2%	
Capacity Value Solar, %	25.0%	18.0%	10.0%	32.0%	30.0%	15.0%	0.0%	35.0%	35.0%	
Capacity Value Solar, MW	350	437	1,400	33	65	243	0	4	5	
Offshore Wind, MW	0	0	0	0	0	0	0	2000	5000	
Onshore Wind, MW	4,500	6,060	17,500	2,140	2,990	4,790	603	603	603	
Total Wind Power, MW	4,500	6,060	17,500	2,140	2,990	4,790	603	2,603	5,603	
Grid Penetration Wind, % of total capacity	21.0%	23.4%	37.3%	28.6%	35.4%	40.3%	18.2%	43.8%	68.9%	
Capacity Value Wind, %	17.0%	17.0%	12.0%	19.0%	18.0%	17.0%	20.0%	19.0%	17.0%	
Capacity Value Wind, MW	765	1030	2100	407	538	814	121	495	953	
Total Variable Capacity Value, MW	1,115	1,468	3,500	440	603	1,057	121	498	957	
Total Variable Capacity Value, % of grid capacity	5.2%	5.7%	7.5%	5.9%	7.1%	8.9%	3.6%	8.4%	11.8%	

Table 2.3.1: Determining Dispatchable Reserves for Variable Generation Capacity (Canada NetZero Scenario)

Table 2.3.2: Determining Dispatchable Reserves for Variable Generation Capacity (Current Measures Scenario)

Current Measures	Alberta			Saskatchewan			Nova Scotia		
Scenario, MW	2025	2030	2035	2025	2030	2035	2025	2030	2035
Total capacity, MW	20,115	24,327	26,277	6,926	7,614	9,208	3,423	4,219	3,250
Solar (Distributed), MW	188	300	550	64	96	811	1	5	8
Solar (Utility scale), MW	1,500.0	1,500.0	3,500.0	20	60	90	0.37	0.37	0.37
Total Solar Power, MW	1,688	1,800	4,050	84	156	901	1	5	8
Grid Penetration Solar, % of total capacity	8.4%	7.4%	15.4%	1.2%	2.0%	9.8%	0.0%	0.1%	0.2%
Capacity Value Solar, %	20%	21%	17.50%	30%	28%	19%	35%	35%	35%
Capacity Value Solar, MW	338	378	709	25	44	171	0.48	2	3

Onshore Wind, MW	2,850	3,750	3,750	1,800	2,630	3,280	603	657	828
Total Wind Power, MW	2,850	3,750	3,750	1,800	2,630	3,280	603	657	828
Grid Penetration Wind, % of total capacity	14.2%	15.4%	14.3%	26.0%	34.5%	35.6%	17.6%	15.6%	25.5%
Capacity Value Wind, %	18%	17%	17%	19%	18%	17%	19%	19%	19%
Capacity Value Wind, MW	513	638	638	342	473	558	115	125	157
Total Variable Capacity Value, MW	851	1,016	1,346	367	517	729	115	127	160
Total Variable Capacity Value, % of grid capacity	4.2%	4.2%	5.1%	5.3%	6.8%	7.9%	3.4%	3.0%	4.9%

Capacity value levels used in Tables 2.3.1, 2.3.2 are based on [35, Fig. 5] for wind power; and [37, Fig. 11] for solar PV.

Tables 2.3.1, 2.3.2 show that Variable Capacity Value indicates considerable dispatchability reserves required in every province adding variable generation to achieve the Clean Grid 2035 objective. This is specifically important in Alberta, Saskatchewan and Nova Scotia promptly growing their variable resources. In the Canada NetZero scenario (table 2.3.1) within 2025 to 2035 period variable dispatchability reserves in Alberta will grow from 5.2% to 7.5%, in Saskatchewan – from 5.9% to 8.9%, and in Nova Scotia - from 3.6% to 11.8% of provincial grid capacity.

A summary of Variable Dispatchability Reserves needed in Canada and their growth in 2025-2035 in NetZero scenario is shown in Table 2.3.3 below:

Table 2.3.3: Variable Dispatchability Reserves needed in Canada by 2035

NetZero Scenario: Variable Dispatchability Reserves needed, MW	2025	2030	2035
Eastern Canada:			
Newfoundland and Labrador	16	18	19
Nova Scotia	121	498	957
Prince Edward Island	75	100	101
New Brunswick	93	107	442
Quebec	782	805	1,025
Ontario	1,879	2,223	3,211
Subtotal Eastern Canada:	2,966	3,751	5,756
Western Canada:			
Manitoba	68	102	105
Saskatchewan	440	603	1,057
Alberta	1,115	1,468	3,500
British Columbia	1,024	1,626	2,231
Subtotal Western Canada:	2,647	3,798	6,894
Total Canada	5,613	7,549	12,649

III. EXPECTED RESULTS AND OUTCOMES

- a) Clean Electricity Sources for Dispatchability Reserves
 - i. Dispatchable Renewable Sources

Within the Clean Grid 2035 vision it is important that variable dispatchability reserves come from dispatchable renewable sources. In Canada's environmental context two highly powerful dispatchable energy sources are available in the country: reservoir-based hydropower and deep geothermal power.

From an immediate readiness standpoint, reservoir-based hydro power can be seen as a strategic dispatchable renewable source available for load-

matching (within a few hours) and possibly for peakmatching (within a few minutes).

Specifically, major reservoir-based hydropower resources in Newfoundland and Labrador, Quebec and Manitoba may be used as dispatchability reserves for deploying variable resources in these – and neighbouring – provinces.

However, it is important to note that using shares of these hydropower sources as dispatchability reserves may reduce their ability to export electricity to the U.S.

Deep geothermal power sources, while not commercially tested in Canada, provide even higher opportunities for Clean Grid 2035 and beyond. Located in the area with very high geothermal resources bordering Alberta, British Columbia, and Yukon [geothermal references], these sources are realized with Enhanced Geothermal Systems (EGS). As a very efficient highly dispatchable resource with capacity factor of 90%, EGS is seen as a strong competitor to any clean electricity solutions considered in Western Canada. Technical and economic aspects of EGS are discussed in Section 4 of this paper.

ii. Hydropower: Changing the Role

Changing the role of reservoir-based hydropower resources from being export-focused to

becoming dispatchability reserves-focused to promptly deploy variable generation across the country presents a strategic opportunity for Clean Grid 2035.

From an economic angle, existing (and growing) power capacity should be seen firstly for meeting electricity demand and related dispatchability requirements, and only secondly for electricity exports. Because of the changes in variable capacity in each of the provinces' electricity generation mix, current export practices should be reviewed/upgraded to establish these priorities. Provincial generation capacity mix should clearly define changes in interconnections between provide variable the provinces to dispatchability reserves.

Favourable conditions for interchange with neighboring provinces should be established within the "electric federalism" context to make this a winning strategy for the provinces contributing variable dispatchability reserves, and for Canada in general.

iii. Interchange Resources as a Key Asset

Interchange resources including interprovincial out/in flows and exports/imports may be generally defined as a difference between Electricity Demand and Generation in the provinces. This difference includes transmission and distribution losses.

NetZero Scenario: Resources for Interchange, TWh	2025	2030	2035
Eastern Canada:			
Newfoundland and Labrador	32.84	32.47	32.43
Nova Scotia	-4.17	0.40	6.15
Prince Edward Island	-0.53	-0.51	-0.19
New Brunswick	-3.38	-6.67	-3.41
Quebec	20.56	35.06	36.72
Ontario	-9.60	-9.83	18.55
Western Canada:			
Manitoba	7.24	14.47	20.51
Saskatchewan	-0.33	-0.50	-1.03
Alberta	8.77	9.63	11.32
British Columbia	2.02	-5.07	-5.92

Table 3.3.1: Interchange Resources*

*Positive figures show interprovincial outflows and exports. Negative figures show interprovincial inflows and imports.

A simplified methodology for defining a part of interchange resources available as variable dispatchability reserves using EF2023 data may be presented as follows.

G = D x (1+TLF+DLF) + IF, or

IF = [G-Dx (1+TLF+DLF)], and

I = DR + IF + EF, and

 $DRC = DR/(CF \times 8760)$, where:

TLF – Transmission loss factor (%)

DLF – Distribution loss factor (%)

G – Generation (TWh)

D – Demand (TWh)

IR – Interchange Resource (TWh),

IF – Interprovincial Flow (TWh),

EF - Export Flow (TWh),

DR – Dispatchability Reserves as a potential Interchange component (TWh)

DRC - Dispatchability Reserves Capacity (MW)

CF – Capacity factor of dispatchability reserve - related generation source, e.g., hydro power or geothermal power (%)

Calculations based on EF2023 data (see Table 3.3.1) show that Newfoundland and Labrador, and Quebec in Eastern Canada and Manitoba in Western Canada have interchange resources based on reservoirbased hydropower that can be used as dispatchability reserves. Nova Scotia and Alberta cannot use their resources for variable dispatchability planning.

However, due to long-term agreements between Newfoundland and Labrador and Quebec,

generation for variable dispatchability applications is limited to Muskrat Falls Generation Station (4.5 TWh annual at 62.3% capacity factor). With Quebec hydro capacity at 73.6% capacity factor (e.g., transmitting electricity from Churchill Falls station in NL) and Manitoba hydro capacity at 75% capacity factor, the sources for variable dispatchability reserves are seen as follows:

Table 3.3.2: Interchange Resources versus Variable Dispatchability Reserves Needed

NetZero Scenario: Interchange Resources Capacity, MW	2025	2030	2035
Newfoundland and Labrador	824	824	824
Quebec	941	2,769	2,319
Manitoba	830	1,880	2,734
Total Canada	2,595	5,473	5,877

NetZero Scenario: Variable Dispatchability Reserves needed, MW	2025	2030	2035
Subtotal Eastern Canada:	2,966	3,751	5,756
Subtotal Western Canada:	2,647	3,798	6,894
Total Canada	5,613	7,549	12,649

Comparing the dispatchability reserves sources and needs, we see that there is a clear gap between the sources and required uses in variable dispatchability reserves, and solutions should be discussed to address this dispatchability gap.

iv. Realizing Clean Dispatchability Reserves Strategy

Below are some examples describing possible realization of the "hydropower-as-a-cleandispatchability-reserve" strategy in Eastern and Western Canada, using interchange capacity as a source of variable dispatchability reserves.

a. Eastern Canada

In the Canada NetZero scenario, the needs for dispatchability reserves may be as follows.

(1) Variable generation growth in Nova Scotia

In Eastern Canada, hydropower capacity in Newfoundland and Labrador presented by Muskrat Falls Generating Station may be considered as a major source for variable dispatchability reserves for Nova Scotia.

By 2030 Nova Scotia plans to deploy 5 GW of offshore wind capacity to start exporting electricity. Dispatchability reserves required for variable capacity in Nova Scotia present 498 MW in 2030 and 957 MW in 2035 (see Table 2.3.3.). The installed capacity of Muskrat Falls Generating Station (NL) is 824 MW. It will provide 60% of its capacity to ensure related capacity value in Nova Scotia's planning reserves only for 2.6 GW of wind power in 2030. In 2035 with expected 5.6GW of wind power in Nova Scotia, the full capacity of Muskrat Falls Generating Station will not be enough, and required difference in capacity would be required from Quebec.

NetZero Scenario	2025	2030	2035
Muskrat hydro capacity, MW	824	824	824
Muskrat capacity factor, %	62.30%	62.30%	62.30%
Variable capacity in Nova Scotia, MW	604	2,613	5,616
Variable dispatchability reserves needed in Nova Scotia, MW	121	498	957
Muskrat hydro capacity available for electricity export, MW	703	326	0
Nova Scotia's purchase of dispatchability reserves from Quebec, MW	0	0	133

Table 3.4.1: Variable dispatchability reserves for Nova Scotia

(2) Clean dispatchability needs in Prince Edward Island, New Brunswick, and Ontario

In Eastern Canada, the provinces of Prince Edward Island, New Brunswick and Ontario do not plan to export electricity and do not have available reserves for variable capacity. The variable dispatchability needs of these provinces are as follows:

Table 3.4.2: Variable dispatchability reserves for Prince Edward Island, New Brunswick, and Ontario

NetZero Scenario	2025	2030	2035
Variable capacity in Prince Edward Island, MW	358.5	484.7	484.8
Dispatchability reserves for variable capacity required for PEI, MW	75.3	99.8	101.1
Variable capacity in New Brunswick, MW	430.2	488.2	2,297.7
Dispatchability reserves for variable capacity required for New Brunswick, MW	93.2	106.6	441.8
Variable capacity in Ontario, MW	10,750.6	13,792.7	23,199.7
Dispatchability reserves for variable capacity required for Ontario, MW	1,879.3	2,222.6	3,210.9

As shown in Table 3.4.2, while very minor support in 2025 may be needed to support dispatchability reserves in Prince Edward Island and New Brunswick, much higher need is seen with dispatchability reserves for variable capacity in Ontario.

(3) Variable generation growth in Quebec

According to Canada Energy Regulator [18], variable capacity in Quebec is expected to grow from 4,580 MW in 2025 to 5,840 MW in 2035. Availability to use interchange capacity based on hydro power for variable dispatchability reserves (calculated at 73.6% capacity factor) in Eastern Canada is shown in Table 3.4.3. It includes opportunities to address the needs of Nova Scotia, Prince Edward Island, New Brunswick, and Ontario.

	<u> </u>		~			<u> </u>
Table 3.4.3 [•]	Quebec	Interchange	Capacity	[,] available f	or Fastern	Canada
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NetZero Scenario	2025	2030	2035
Quebec interchange availability, TWh	6.07	17.85	14.95
Quebec hydro capacity for electricity export/interprovincial outflows, MW	941	2,769	2,319
Variable capacity in Quebec, MW	4,580	4,660	5,840
Dispatchability reserves needed for variable capacity in Quebec, MW	782	805	1,025
Quebec interchange capacity available for dispatchability reserves, MW	159	1,964	1,294
Dispatchability reserves needed for variable capacity in Nova Scotia, MW	0	0	133
Dispatchability reserves needed for variable capacity in Prince Edward Island, MW	75	100	101

NetZero Scenario	2025	2030	2035
Dispatchability reserves needed for variable capacity in New Brunswick, MW	93	107	442
Dispatchability reserves needed for variable capacity in Ontario, MW	1,879	2,223	3,211
Quebec interchange capacity available after dispatchability reserves purchase by Nova Scotia, Prince Edward Island, New Brunswick and Ontario, MW	-1,889	-465	-2,593
Possible support from Manitoba, MW	762	1,778	2,629
Dispatchability reserves balance in Eastern Canada with Manitoba support, MW	-1,127	0	0
Interchange resources available in Manitoba after support to Ontario, MW	0	1,312	36

Summarizing dispatchability aspects in Canada NetZero scenario: figures in Tables 3.4.1-3.4.3 show that dispatchable hydropower resources in Eastern Canada (such as Newfoundland and Labrador, and Quebec) can provide variable dispatchability reserves for grid planning support for the Maritimes but are not sufficient for addressing the clean dispatchability reserves needs of variable capacity in Ontario (see Table 3.4.3). However, this may be addressed in 2030 and 2035 by receiving dispatchability reserves support from Manitoba. b. Western Canada

In Western Canada opportunities to use hydropower as dispatchability reserve look as follows.

The reservoir-based hydropower resources of Manitoba have their total capacity of 2.3 GW (based on [39-41]). The hydro power resources in Manitoba, focused on electricity export, can be redirected to supporting dispatchability reserves in the province and beyond in Western Canada. A very small share of these resources can be supporting variable generation in Manitoba (see Table 3.4.4 below).

Canada NetZero Scenario	2025	2030	2035
Manitoba hydro capacity, MW	6,070	7,590	7,670
Manitoba interchange capacity available, MW	830	1,880	2,734
Manitoba variable capacity, MW	320	466	476
Dispatchability reserves for variable capacity required for Manitoba, MW	68	102	105
Manitoba interchange capacity available after its dispatchability reserve adjustment, MW	762	1,778	2,629

The Manitoba hydro capacity available for export after its dispatchability reserve adjustment can be considered to support the clean dispatchability reserves needs of variable capacity in Ontario in coordination with Quebec (Table 3.4.2). Or – it can be used to support dispatchability reserves needs of variable capacity in Saskatchewan:

Canada NetZero Scenario	2025	2030	2035
Saskatchewan variable capacity, MW	2,244	3,206	6,410
Dispatchability reserves for variable capacity required for Saskatchewan, MW	440	603	1,057
Manitoba interchange capacity available after Saskatchewan dispatchability reserve adjustment, MW	322	1,175	1,572

However, Manitoba interchange capacity can only partially cover the needs for variable dispatchability reserves in Alberta:

Canada NetZero Scenario	2025	2030	2035
Alberta variable capacity, MW	5,901	8,490	31,500
Dispatchability reserves for variable capacity required for Alberta, MW	1,115	1,468	3,500
Manitoba interchange capacity available after Saskatchewan and Alberta dispatchability reserve adjustment, MW	-793	-293	-1,928

Also, the needs for dispatchability reserves for covered and have to be addressed by other clean variable capacity required for British Columbia are not dispatchability reserves sources:

Table 3.4.7: Variable dispatchability reserves for British Columbia

Canada NetZero Scenario	2025	2030	2035
British Columbia variable capacity, MW	5,721	11,710	16,890
Dispatchability reserves for variable capacity required for British Columbia, MW	1,024	1,626	2,231

Overall, should Manitoba provide their exportoriented capacity as clean dispatchability reserves to Ontario or sell electricity into the U.S., the following dispatchability reserves would be needed for Saskatchewan, Alberta, and British Columbia in total:

Table 3.4.8: Variable dispatchability reserves for Saskatchewan, Alberta, and British Columbia

Canada NetZero Scenario	2025	2030	2035
Dispatchability reserves for variable capacity required for Saskatchewan, Alberta, and British Columbia – total*, MW	2,579	3,696	6,789

*This is based on a hydropower capacity factor of 75% (close to hydropower in Manitoba).

As within the Clean Grid 2035 timeframe neither Saskatchewan nor Alberta or British Columbia probably will have available export or other clean dispatchability reserves supporting their variable capacity, other clean dispatchability resources can be used in Western Canada.

One of such sources that is seen as highly attractive for Western Canada's use is Enhanced Geothermal Systems (EGS) located in the area with very high geothermal resources bordering Alberta, British Columbia, and Yukon [11]. As a very efficient highly dispatchable resource with capacity factor of 90%, EGS is seen as a strong competitor to any solutions being considered in Alberta and British Columbia. While technical and economic aspects of EGS are discussed in Section 4 of this paper, here we only indicate the figures relating to dispatchability reserve needs.

To establish EGS dispatchability reserve needs, reservoir-based hydro and enhanced geothermal capacity should be matched for electricity generation. This can be defined using a capacity factor ratio that can be applied in reserve planning:

EGS capacity (MW) = hydropower capacity (MW) x CFR,

where CFR = hydropower capacity factor/EGS capacity factor is capacity factor ratio.

Using hydropower capacity factor of 75% and factor ratio of 0.8333 that is used for adjusting EGS EGS capacity factor of 90%, we determine capacity dispatchability reserve:

3.4.9: Enhanced Geothermal Systems-based dispatchability reserves for Saskatchewan, Alberta, and British Columbia

Canada NetZero Scenario	2025	2030	2035
Enhanced Geothermal Systems-based dispatchability reserves for variable capacity in Saskatchewan, Alberta and British Columbia, MW	2,149	3,080	5,657

v. Integrating Dispatchable Renewable Fleets

Enhanced geothermal systems can be used not only in planning and deployment of clean dispatchability reserves, but they can also be effectively competing with other resources in EF2023 within the Glean Grid 2035 timeframe. For example, Table 3.5.1 below shows the current Canada NetZero scenario for Alberta:

Canada NetZero	Capacity, MW			Capacity, MW Generation, TWh		
ALBERTA	2025	2030	2035	2025	2030	2035
Solar (Distributed)	221	500	1,000	0.33	0.76	1.51
Solar (Utility scale)	1,180	1,930	13,000	2.09	3.47	23.98
Onshore Wind	4,500	6,060	17,500	16.05	21.53	65.15
Hydro	894	894	894	1.65	1.65	1.35
Hydrogen	0	0	0	0.00	0.00	0.00
Natural Gas	14,300	14,000	8,660	68.85	66.07	5.28
Natural Gas with CCUS	0	2,090	4,290	0.00	11.70	21.23
Oil	7	7	7	0.02	0.00	0.00
Battery Storage	90	90	90			
Bioenergy	286	286	286	1.41	1.60	1.04
Bioenergy with CCUS	0	0	728	0.00	0.00	5.74
Geothermal with EGS						
Uranium SMR	0	0	459	0.00	0.00	3.20
Total	21,478	25,857	46,914	90.4	106.8	128.5

This scenario can be effectively transformed in a scenario with EGS deployment:

Table 3.5.2: Canada NetZero scenario for Alberta	 adjusted by 	EGS capacity
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Canada NetZero	C	apacity, MW		Generation, TWh		
ALBERTA	2025	2030	2035	2025	2030	2035
Solar (Distributed)	221	500	1,000	0.33	0.76	1.51
Solar (Utility scale)	1,180	1,930	6,430	2.09	3.47	11.86
Onshore Wind	4,500	6,060	10,060	16.05	21.53	37.45
Hydro	894	894	894	1.65	1.65	1.35
Hydrogen	0	0	0	0	0	0
Natural Gas	14,300	3,000	0	68.85	14.16	0.00
Natural Gas with CCUS	0	2,090	4,290	0.00	11.70	21.23
Oil	7	7	7	0.02	0	0
Battery Storage	90	90	90			
Bioenergy	286	0	0	1.41	0.00	0.00
Bioenergy with CCUS	0	0	0	0	0	0
Geothermal with EGS	0	6,788	6,986	0	53.51	55.08
Uranium SMR	0	0	0	0	0	0
Total	21,478	21,359	29,758	90.4	106.8	128.5

Furthermore, Enhanced Geothermal Systems (EGS) located in the area with very high geothermal resources bordering Alberta, British Columbia, and Yukon [11], can be used for dispatchability resources/load matching not only in Western Canada, but will allow for addressing these needs in Ontario and in Eastern Canada (see Section 4).

Overall, the proposed approach to using hydropower as a variable dispatchability reserve from Newfoundland and Labrador, and Quebec for Eastern Canada, and combining hydropower in Manitoba and geothermal power in Alberta/Yukon as dispatchability reserves for Western Canada makes variable resources like wind and solar dispatchable, upgrading all power grids in Canada to Clean Grid practices in 2035 and further in 2050.

Using dispatchable hydropower and geothermal power together with wind and solar power would make all generating capacity in Canada dispatchable and would establish its leading clean dispatchability practices in North America. It would also present an opportunity for Dispatchable Integrated Renewable Fleets in all Canadian provinces and beyond.

b) Geothermal Technology as a Strategic Opportunity

i. Strategic Opportunities with Geothermal

Dramatically scaling up clean electricity generation to meet the Clean Grid 2035 objective means leveraging and promptly deploying strategic solutions Canada has at hand. One of these very few strategic solutions for addressing the net-zero electricity gap in the country is Geothermal Power Generation.

While geothermal resources in Canada have massive potential to provide clean energy across the country, geothermal power generation has largely remained undeveloped [20]. Today, with Canada's leadership in energy transition and total electrification, and Canada Energy Regulator's detailed look into Canada's Energy Future, enhanced geothermal generation opportunities must be viewed from a crucial strategic angle.

It is generally well known that geothermal generation provides clean, renewable, round-the-clock electricity, not depending on weather, season, and time of day; it emits little or no greenhouse gases, and has a small environmental footprint, very competitive to renewable resources like wind, solar or hydro [42]. What is not often mentioned is that enhanced geothermal generation brings to power grids in Canada two unique opportunities: a powerful source of dispatchable baseload, and a "power storage" for dispatchability reserves allowing for unlimited growth of variable renewables like wind or solar. Understanding this in the context of the Clean Grid 2035 commitment, Canada must promptly strengthen geothermal power generation in Western provinces - moving from a "lagging behind" position in North America, and globally, to a world leader in exporting deep geothermal expertise and technology internationally [13].

ii. Geothermal Resources in Canada

High temperature geothermal resources in Canada are a part of the Pacific Ring of Fire, a tectonic belt of volcanoes and earthquakes [43], and the related Canada's Pacific Rim. Volcanic belts are common in the Canadian Cordillera [11, 14]. British Columbia, Yukon and Northwest Territories are home to a region of volcanoes and volcanic activity in the Pacific Ring of Fire.

Geothermal resources of the Pacific Rim are the most efficient and economic means to generate geothermal power, with high temperature resources (>150°C) typically targeted for highly dispatchable electricity generation.

These high temperatures allow very high potential for electricity generation in regions of northeastern British Columbia and southern Yukon, northern Alberta, and southern Northwest Territories. Regional temperatures suitable for electricity generation, 150°C or more, can be reached at relatively shallow depths of 3.5-4.5 km in northwestern Alberta and

northeastern BC. For communities in the southern Mackenzie Corridor and in southwest Yukon, temperatures >150°C can be reached at depths of 3.5-5 km.

To estimate the thermal energy, or heat content, for deploying geothermal power plants, a 4 x 4 km rock mass, 1 km thick (16 km³ total volume) was considered by S. E. Grasby et al in [11]. Cooling this rock mass from an initial temperature of 150° C to a final temperature of 30° C results in $5x10^{18}$ Joules, or 1.39 PetaWatt-hours (PWh).

The actual accessible and usable geothermal energy resource is estimated by applying a factor of 0.02 of in-place thermal energy, or 1 x 10¹⁷ J (27.8 TWh) for the same rock volume of 16 km³. Comparing 27.8 TWh power output of this geothermal unit with electricity demand in 2023 in British Columbia (65.10 TWh), Alberta (80.69 TWh) or Saskatchewan (25.45 TWh) shows a very limited number of units (e.g. one geothermal unit for transmission to Saskatchewan or three geothermal units in Alberta) that can cover the electricity needs in these provinces.



Fig. 4.2.1: Heat Energy at 3.5 km depth [11]



Fig. 4.2.2: Depth (km) to 150°C temperature [11]

It has been found [12] that multiple locations of heat value resources are available at moderate depths which have already been reached in oil and gas drilling operations. Based on petroleum industry experience in the Western Canadian Sedimentary Basin (WCSB), it is common to drill 4 to 6 km deep wells in deeper parts of this area, and technology to achieve such depths is readily available.

Many locations with enhanced geothermal generation potential in the WCSB occur in northeastern British Columbia, parts of northwestern Alberta and central Alberta (including the Lac La Biche high), and in Saskatchewan (Williston Basin high). Also, in the WCSB these depths are mainly reached below the sedimentary cover. These sediments form an effective thermal blanket that decrease the depth required to reach effective temperatures for enhanced geothermal development. As drilling through sedimentary rocks is less expensive than in the areas of crystalline rock, enhanced geothermal deployment in these areas is more economically attractive.

Specifically, the Alberta Basin area is seen as a practical approach for geothermal electricity generation [12]. Opportunities of access to the Northern Lights Transmission line and the Edmonton-West coal power corridor were reviewed for power transmission within the Alberta electricity system to make this geothermal power generation economic and leverage its highly efficient dispatch.

iii. Enhanced Geothermal Systems for Electricity Generation

Enhanced Geothermal Systems (EGS) bring geothermal energy for electricity generation from heat produced in the subsurface. This heat is generated from natural radiogenic decay of elements in the upper crust as well as primordial heat generated from the formation of the planet.

EGS use fluid injected deep underground under carefully controlled conditions; this fluid absorbs energy from hot rock formations and carries this energy to the surface to drive turbines and generate electricity in flash steam or binary-cycle geothermal power plants [44,45].

Modern EGS are divided into two major groups: open-loop and closed-loop systems. The open-loop systems have fluid pumped down injection wells into hot rock formations, migrate through the hot rock and while collecting heat, get captured by extraction wells, and pumped back to the surface where the heat is converted into electricity [46]. The wells are often drilled horizontally to maximize the volume of hot rock exposed to the fluid. The closed-loop systems have the fluid pumped into a well contained within the underground pipes, recovered and re-used. The closed-loop EGS presents two approaches. A single-well approach uses concentric pipes to pump a heat transfer fluid down a vertical wellbore and along a directional wellbore, have it make U-turn and flow back within a concentric pipe. A multiple-well (doublet) approach has the fluid conveyed back to the surface up a second vertical wellbore to be pumped back to the injection wellbore.

Leading examples of EGS solutions in North America are presented by such technology developers as Fervo Energy (Houston, Texas) and Eavor Technologies Inc. (Calgary, Alberta) [47].

Fervo Energy presents first-of-a-kind EGS horizontal doublet well system, consisting of an injection and production well pair within a high-temperature, hard rock geothermal formation [48] (see Fig. 4.3.1).



Fig. 4.3.1: A cross-section of the horizontal doublet EGS system and deep vertical monitoring well [48] Credits to Fervo Energy

Eavor Technologies presents a Eavor-Loop[™], consisting of large U-tube shaped well with 2 multilaterals. Eavor-Lite[™] Pilot (see Figure 4.3.2) is a fullscale prototype of the Eavor-Loop[™]. The laterals are approximately 1700m long and are placed in the Rock Creek formation at depth of 2400m.



Fig. 4.3.2: Schematic of Eavor-Lite[™] Pilot[49,50]. Credits to Eavor Technologies

EGS use human-made reservoirs to inject fluid and extract economical amounts of heat from low permeability and/or low porosity geothermal resources. The fluid in EGS carries energy to the surface through wells, driving turbines and generating electricity [44,45].

The high capacity factor of geothermal power (90%) makes it particularly attractive as a dispatchable renewable resource.

iv. Economics of Enhanced Geothermal Systems

While geothermal energy resources in Canada are unique and attractive because of their geoeconomic positioning in Western Canada, Enhanced Geothermal Systems (EGS) for electricity generation in Canada present a longer-term objective in energy transition process towards Net Zero [11,14].

To support this statement, three major parameters of EGS should be reviewed to analyse costs and risk factors of deploying this technology: capital expenditures (CAPEX) covering equipment, engineering and deployment costs of a plant, operational expenditures (OPEX) covering fuel, maintenance, and support costs of this plant, and levelized cost of energy (LCOE) indicating the net present cost of electricity generation over the anticipated lifetime of the plant.

Table 4.4.4 below presented by [egs16] compares different power-station options based on their CAPEX and LCOE. CAPEX represents the upfront funds needed for plant development, and LCOE compares the lifetime costs of different energy systems using a 30-year payback period:

	Electricity source	CAPEX (\$/kW)	LCOE (\$/kWh)	Cost Estimate Date, Notes, Source
1	Geothermal (hydrothermal)	2,400 - 6,200	0.07 – 0.12	(2019) ²
2	Geothermal ('near hydrothermal' EGS)	9,000 - 10,000	0.1-0.3	(2019) ²
3	Geothermal ('deep' [3-6km] EGS)	20,000 - 46,000	0.16 – 0.42	(2019) (low=flash, high=binary cycle) ³
4	Hydroelectric	2,500 - 16,000	0.06 - 0.36	(2019)4
5	Solar (Utility PV)	~1,400	0.03 - 0.05	(2019) (w/o battery storage) ⁵
6	Wind (land)	~1,450	0.25 – 0.08	(2019) ⁶
7	Nuclear	~6,800	~0.08	(2019) ⁷
8	Coal	4,000 - 6,200	~0.09 - ~0.16	(2017) (low = new plant; high = with CCS (carbon capture + storage) ⁸
9	Natural Gas	920 - 3,300	~0.06 - ~0.16	(2017) (low = turbine combined cycle; high = same + CCS) ⁹
10	Tidal	"high"	0.2 - 0.45	(2020) (~ 535MW in operation worldwide; most 'tidal barrage' (~522MW) ¹⁰
11	Wave	"high"	0.3-0.55	(2020) (< 3MW in operation worldwide) ¹⁰

Table 4.4.4: Electricity	<pre>/ source CAPEX and LCOE, USD </pre>	13]
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According to the Canada Energy Regulator [51], in 2021 the capacity cost for a geothermal power plant was estimated between US\$4,500 to \$6,050 per kilowatt (kW) of capacity, and the levelized cost of energy - US\$56 to \$93 per megawatt hour (MWh).

Geothermal plants, like hydroelectric and nuclear plants, are capital-intensive - in the case of nearhydrothermal and deep EGS plants, far more so than wind or solar installations [13]. However, as noted earlier, these plants can often be built out incrementally, starting with a small pilot plant and then scaling up. This option is not available with nuclear or hydroelectric plants.

In terms of geothermal CAPEX, drilling and well completion dominate the expenditures with on average 54 percent of all capital costs (see Fig. 4.4.1 [13, 52]):





From environmental risk angle geothermal plants produce significantly less footprint and related landscape disturbance than solar, wind, and hydroelectricity indicating much smaller risks to lands and ecosystems. Power density (in watts generated per square meter of power plant footprint) of competing clean electricity technologies is presented in Table 4.4.2 below [13]:

Electricity source	Range of power density (W/m²)	Mean power density (W/m²)
Utility-scale PV	4.2 – 7.5	5.8
High-temp geothermal (>250°C)	1.6-8.4	4.9
Offshore wind	2.2 - 6.3	4.2
Onshore wind	2.4 - 3.8	3.1
Low-temp geothermal (<250°C)	0.5 – 2.9	1.6
Large hydro	0.2 - 1.0	0.5
Oil crops	N/A	0.2
Wood crops	N/A	0.2

Table 4.4.2: Comparative Power densities of selected net-zero energy sources [13, 53]

v. Geothermal Fuel vision in North America

a. United States

On September 8th, 2022, the Enhanced Geothermal Shot was announced in Houston, Texas. Its target is to reduce the cost of EGS by 90%, to \$45 per megawatt hour by 2035.

The Enhanced Geothermal Shot is part of the U.S. Department of Energy's Earthshots[™] Initiative to tackle key remaining technical challenges to reaching

U.S. climate goals and leverage economic opportunities [44, 45, 54].

While today a small portion of the geothermal energy is accessible with current technology in the U.S., research and innovation to advance enhanced geothermal systems (EGS), which create human-made reservoirs to access energy, is expected to unlock geothermal resources and put new, clean, dispatchable electricity on the grid.

According to the Advanced Technology Innovation approach considered with substantial drilling and EGS advancements, EGS power plants are assumed to be built with 100 MW of capacity to maximize project efficiency [54]. Based on GeoVision Analysis [55,56] EGS future growth is forecast.

Three scenarios are considered in this analysis: Business-as-Usual (BAU), Improved Regulatory Timeline (IRT) and Technology Improvement (TI). In the BAU scenario, installed geothermal capacity increases from 2,542 MWe in 2016 to 5,924 MWe by 2050. The IRT scenario estimates 12,891 MWe of total installed geothermal capacity by 2050. In the TI scenario, total installed geothermal capacity reaches 60,701 MWe by 2050.

2019, developing, testing, As of and accelerating breakthroughs in EGS technologies to advance the uptake of geothermal resources has been led by the Frontier Observatory for Research in Geothermal Energy - Utah FORGE, a dedicated underground field laboratory sponsored by the U.S. Department of Energy. Working in coordination with Utah FORGE, in July 2023 Fervo Energy announced that it successfully completed a full-scale well test in Nevada that confirmed the commercial viability of its nextgeneration technology (see Fig. 4.5.1, 4.5.2). A nextgeneration geothermal plant backed by Google has started sending carbon-free electricity to the grid in Nevada, where the tech company operates some of its massive data centers [57].



Fig. 4.5.1: Fervo Energy's 3.5-megawatt enhanced geothermal plant in Nevada. Credits to Google/Fervo Energy



Fig. 4.5.2: Fervo uses horizontal drilling techniques to tap the earth's heat. Credits to Fervo Energy

b. Canada

The Government of Canada is advancing the country's transition to a low-carbon economy in Canada through strategic investments and innovative partnerships including geothermal energy.

In June 2022, federal funding was provided to Novus Earth to execute a front-end engineering design (FEED) study for the Latitude 53 geothermal energy project with a closed-loop enhanced geothermal system in the community of Hinton, Alberta. This investment was provided by Natural Resources Canada's Smart Renewables and Electrification Pathways (SREPs) program that provides support for smart renewable energy and electrical grid modernization projects.

In October 2023, Eavor Technologies Inc. (Eavor), Calgary, Alberta, a pioneer in the field of advanced geothermal energy solutions, announced the successful completion of \$182 million in financing of its Eavor-Loop[™] enhanced geothermal system solution. This significant investment will enable Eavor to accelerate the development and deployment of its revolutionary geothermal technology. The equity round was led by OMV AG, with participation from Canada Growth Fund ("CGF"), Japan Energy Fund, Monaco Asset Management and Microsoft's Climate Innovation Fund as well as from existing investors.

In February 2024 Eavor announced a significant addon investment from Kajima Corporation, one of Japan's construction giants [58]. This strategic alliance promises to accelerate the global transition to sustainable energy by facilitating the expansion of Eavor's innovative technology across various sectors (see Fig. 4.5.3).



Fig. 4.5.3: Eavor Technologies Secures Major Investment from Kajima for Geothermal Advancement [57]. *Credits to Eavor Energy*

As Canada's federal government is increasing its support of geothermal technology, provincial advances in geothermal are also matching this growth. Specifically, Alberta is strengthening its position to lead development and deployment and attract investment in geothermal industry with a natural geographical advantage, leadership in drilling technology, and extensive oil and gas expertise [59]. Geothermal Resource Tenure Regulation in Alberta [60] today is the primary regulation that deals with the tenure of geothermal leases in Alberta. This new regulation, and amendments to other regulations, took effect on January 1, 2022.

Also, while geothermal development efforts are growing in Canadian provinces, research is underway in Canada's three territories: Yukon, Northwest Territories and Nunavut, to assess geothermal resources of target communities [14]. This includes deep geothermal systems as a long-term objective that may provide sufficient energy to meet communities' heavy heating needs. Results suggest that geothermal technologies can provide important carbon reductions and are economically attractive.

IV. CONCLUSIONS AND RECOMMENDATIONS

1. Clean Grid readiness is a major objective of Canada's Clean Grid 2035 achievements and commitment to make all electricity generation in the country carbon net-zero. Making all the sources of electricity in power grids clean will make a tremendous step in Canada's energy transition and low carbon economy growth.

2. A major effort in cleaning the grid within a decade is focused on decarbonizing power generation in three provinces historically using fossil fuels for growth: Alberta, Saskatchewan, and Nova Scotia.

An outstanding undertaking in cleaning energy generation mix in these three provinces is deploying variable renewables – wind and solar power at very large scale in the country. In the Canada NetZero scenario of energy future presented by Canada Energy Regulator, total capacity of variable renewables in Alberta, Saskatchewan, and Nova Scotia by 2035 is 27.9GW (49% of 56.7 GW) of wind power and 15.6 GW (59% of 26.4 GW) in Canada, and these variable renewables will generate 104TWh (50% of 207.5 TWh) of wind and 29 TWh (64% of 45TWh) of solar power in the country.

- 3. Deploying very large scale of variable renewables in Canada requires an extremely significant power dispatchability effort, allowing the country's power grids to maintain their reliability. Clean Grid 2035 commitment also assumes that all existing and new power dispatchability sources in Canada backing up variable renewables' operations are clean.
- 4. Choosing to have the renewable segment of clean dispatchability sources lead in Canada's Clean Grid efforts and creating renewable dispatchable fleets will make all variable renewables in the country dispatchable. This would make a tremendous change in upgrading Canada's power grids and its contribution to low carbon economy in general.

5. Canada is capable and committed to making this leadership change in dispatchability of variable renewables.

Indeed, Canada's electricity systems historically had been built on extremely strong reservoir-based hydro power in Newfoundland and Labrador, Quebec, Manitoba. These renewable dispatchable resources can be used to back up variable renewables' growth in Alberta, Saskatchewan, and Nova Scotia, and in the country in general.

Canada is also geographically built on geothermal resources. Geothermal resources in the Pacific Rim including the regions of northeastern British Columbia and southern Yukon, northern Alberta and southern Northwest Territories bring very high potential for highly dispatchable electricity generation. Due to their unique position in Western Canada, deep geothermal resources allow for deploying Enhanced Geothermal Systems (EGS) for electricity generation at high scale. Capabilities of Enhanced Geothermal power plants based on very high (90%) capacity factor and dispatchability will provide variable dispatchability reserves in Western Canada that will strengthen and support Canada's Clean Grid 2035 efforts. As a part of these leadership efforts. Canada must catch up with the in positioning and developing U.S. EGS partnerships and investments.

As Canada's federal government is increasing its support of geothermal technology, provincial advances in Enhanced Geothermal Systems led by Canadian clean technology companies such as Eavor Technologies Inc. are also matching this growth.

- 6. Opportunities with current and growing Clean Grid efforts may allow for changing the role of reservoirbased hydro power in Canada from electricity export-oriented to variable renewables dispatchability support-oriented. Backing up the growth of variable renewables will in turn allow for growing export of electricity in Eastern Canada (from offshore fleets in the Atlantic Rim such as Sable Island) and in Western Canada (from geothermal plants in the Pacific Rim such as in northern Alberta).
- 7. Comparison of the dispatchability reserves sources and needs for variable renewables shows that there is a clear gap between the sources and required uses in variable dispatchability reserves, and solutions should be discussed and agreed on to address this dispatchability gap.

Examples describing possible realization of the Clean Dispatchability Reserves Strategy in Eastern and Western Canada, using interchange capacity as a source for variable dispatchability reserves, are presented in Section 3 of this paper. They show that dispatchable hydropower resources in Eastern Canada (such as Newfoundland and Labrador, and Quebec) can provide variable dispatchability reserves for grid planning support for the Maritimes but are not sufficient for addressing the clean dispatchability reserves needs of variable capacity in Ontario (see Tables 3.4.1-3.4.3). However, this may be addressed in 2030 and 2035 by receiving dispatchability reserves support from Manitoba. However, should Manitoba provide its exportoriented capacity as clean dispatchability reserves to Ontario or sell electricity into the U.S., dispatchability reserves would be needed for Saskatchewan, Alberta, and British Columbia (see Table 3.4.8).

- The approach proposed here to using hydropower 8. as a variable dispatchability reserve for Eastern and combining hydropower Canada and geothermal power as dispatchability reserves for Western Canada will make variable renewables dispatchable, upgrading all power grids in Canada to 100% Clean Grid readiness by 2035 and maintaining this Clean Grid commitment in 2050 and beyond. Using dispatchable hydropower and geothermal power together with wind and solar power in Renewable Dispatchable Fleets in Alberta, Saskatchewan and Nova Scotia would make all renewable capacity in these provinces dispatchable, establishing leading clean dispatchability practices in North America. It is an opportunity for Dispatchable Integrated Renewable Fleets present in all Canadian provinces.
- 9. To agree on renewable dispatchable fleets deployment and existing dispatchability reserves commitments from the provinces owning and operating large scale reservoir-based hydro power plants, Canada's "electric federalism" concept and approach should be demonstrated efficiently and promptly. A summary of Variable Dispatchability Reserves needed in Canada and their growth in 2025-2035 in NetZero scenario is shown in Section 2 of this paper. It brings attention to economic pricing solutions for hydro dispatchability assets in Quebec, and Newfoundland Manitoba. and Labrador.
- 10. Scaling up clean electricity generation to meet Clean Grid 2035 objectives means leveraging and promptly deploying strategic solutions Canada has at hand. Although the future of energy in Canada is broader than the economic and technical factors driving the projections in EF2023, some of these factors such as Renewable Dispatchability Reserves for variable renewables, and highly dispatchable Enhanced Geothermal systems and technologies require critical attention and should be very promptly addressed as they touch very sensitive decisions of Canadian provinces and realities of electric federalism in Canada.
Acknowledgments and Conflicts of INTEREST

Acknowledgments: The author is extremely grateful to Marlene Moore for the concept discussions supporting the vision expressed in the manuscript.

The author is also much obliged to John Harker for his strategic review of the manuscript and for thoughtful editing.

Conflicts of Interest: The author declares no conflict of interest.

References Références Referencias

- Department of Finance Canada. (2023, March 28). 1. Chapter 3: A Made-In-Canada Plan: Affordable Energy, Good Jobs, and a Growing Clean Economy. Budget 2023. https://www.budget.canada.ca/2023/ report-rapport/chap3-en.html#a5
- 2. Service Canada. (2024, February 2). Net-zero emissions by 2050. Canada.ca. https://www.cana da.ca/en/services/environment/weather/climatechan ge/climate-plan/net-zero-emissions-2050.html
- З. Canada, N. R. (2023, August 31). Powering Canada Forward: Building a clean, affordable, and reliable electricity system for every region of Canada. https://natural-resources.canada.ca/our-natural-reso urces/energy-sources-distribution/electricity-infrastr ucture/powering-canada-forward-building-clean-affo rdable-and-reliable-electricity-system-for/25259
- 4. Project of the Century Public Policy Forum. (2023, October 17). Public Policy Forum. https://ppforum. ca/publications/net-zero-electricity-canada-capacity/
- 5. Fostering effective energy Transition 2023. (2023, October 9). World Economic Forum, https://www.we forum.org/reports/fostering-effective-energy-transitio n-2023
- 6. Wikipedia contributors. (2024, March 28). Churchill Falls Generating Station. Wikipedia. https://en.wiki pedia.org/wiki/Churchill Falls Generating Station
- Wikipedia contributors. (2024b, March 31). Muskrat 7. Falls Generating Station. Wikipedia. https://en.wiki pedia.org/wiki/Muskrat Falls Generating Station
- Hydro-Québec. (n.d.). Generating stations. https:// 8. www.hydroguebec.com/generation/generating-stati ons.html
- 9. Wikipedia contributors. (2023, January 26). List of generating stations in Manitoba. Wikipedia. https:// en.wikipedia.org/wiki/List of generating stations in Manitoba
- 10. Wikipedia contributors. (2024a, January 9). List of generating stations in British Columbia. Wikipedia. https://en.wikipedia.org/wiki/List of generating stati ons_in_British Columbia
- 11. Grasby, S. E., Allen, D., Bell, S. E., Chen, Z., Ferguson, G., Jessop, A. M., Kelman, M. C., Ko, M., Majorowicz, J., Moore, M. C., Raymond, J., &

Therrien, R. (2012). Geothermal energy resource potential of Canada. https://doi.org/10.4095/291488

- 12. Majorowicz, J. & Moore, M.C. (2008 July). Enhanced Geothermal Systems (EGS) Potential in the Alberta Basin. Alberta Energy Research Institute. http:// www.aeri.ab.ca/sec/new res/docs/Enhanced Geot hermal Systems.pdf
- 13. Cascade Institute. (2024, March 12). Deep Geothermal Superpower: Canada's potential for a breakthrough in enhanced geothermal systems -Cascade Institute. https://cascadeinstitute.org/tech nical-paper/deep-geothermal-superpower/
- 14. Miranda, M. M., Comeau, F., Raymond, J., Gosselin, L., Grasby, S. E., Wigston, A., Dehghani-Sanij, A., Sternbergh, S., & Perreault, S. (2022). Geothermal resources for energy transition: A review of research undertaken for remote northern Canadian communities. Zenodo (CERN European Organization for Nuclear Research). https://doi.org/ 10.5281/zenodo.7882811
- 15. Canadian Climate Institute. (2022, May 4). Electric Federalism: Policy for aligning Canadian electricity systems with net zero. https://climateinstitute.ca/wpcontent/uploads/2022/05/Electric-Federalism-May-4 -2022.pdf
- 16. Wikipedia contributors. (2024b. March 11). Geoeconomics. Wikipedia. https://en.wikipedia.org/ wiki/Geoeconomics
- 17. Dryden, J. (2024, February 16). Ottawa floats new options for electricity rules that drew ire of Alberta and Saskatchewan. CBC. https://www.cbc.ca/news/ canada/calgary/alberta-clean-electricity-regulationsottawa-steven-guilbeault-1.7117495? vfz=medium %3Dsharebar
- 18. Government of Canada, Canada Energy Regulator. (2024, March 28). CER - Canada's energy future. https://www.cer-rec.gc.ca/en/data-analysis/canadaenergy-future/index.html
- 19. Graham. (2024, February 28). Eavor the world's first scalable form of clean baseload power [Video]. Eavor. https://www.eavor.com/
- 20. Why Canada might finally seize its geothermal power potential - BNN Bloomberg. (2023, December 27). BNN. https://www.bnnbloomberg.ca/a-long-overloo ked-climate-solution-geothermal-could-be-in-for-itshottest-decade-yet-1.2015782
- 21. Government of Canada, Canada Energy Regulator. (2024a, March 21). CER - Access and Explore Energy Future Data. https://www.cer-rec.gc.ca/en/ data-analysis/canada-energy-future/2023/accessand-explore-energy-future-data.html
- 22. Harack, B., & Harack, B. (2016, February 24). How can renewables deliver dispatchable power on demand? | Vision of Earth. Vision of Earth | Shaping a Happy, Healthy, and Prosperous Future. https://www.visionofearth.org/industry/renewable-en

ergy/renewable-energy-review/how-can-renewablesdeliver-dispatchable-power-on-demand/

- 23. Wikipedia contributors. (2023b, July 25). *Dispatchable generation.* Wikipedia. https://en.wiki pedia.org/wiki/Dispatchable generation
- 24. Wikipedia contributors. (2024a, January 3). *Ancillary services (electric power)*. Wikipedia. https://en.wiki pedia.org/wiki/Ancillary_services_(electric_power)
- 25. Government of Canada, Fisheries and Oceans Canada. (2007). Canada's Ocean Estate. A Description of Canada's Maritime Zones. https:// waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/4 0622952.pdf
- 26. Wikipedia contributors. (2024d, March 19). Ocean thermal energy conversion. Wikipedia. https://en.wikipedia.org/wiki/Ocean_thermal_energy_conversion
- Ascari, M. B., Hanson, H. P., Rauchenstein, L. T., & Jansen, E. (2012). Ocean Thermal Extractable Energy Visualization- Final Technical Report on Award DE-EE0002664. October 28, 2012. *ResearchGate.* https://www.researchgate.net/public ation/268506159_Ocean_Thermal_Extractable_Ener gy_Visualization-_Final_Technical_Report_on_Awar d DE-EE0002664 October 28 2012
- 28. M-1 reserve margin. (n.d.). https://www.nerc.com/ pa/RAPA/ri/Pages/PlanningReserveMargin.aspx
- 29. Wikipedia contributors. (2024c, January 15). *Resource adequacy.* Wikipedia. https://en.wikipe dia.org/wiki/Resource_adequacy
- 30. *Resource adequacy.* (n.d.). NREL. https://www.nrel. gov/research/resource-adequacy.html
- Tuohy, A. (2024-02-26). Probabilistic Resource Adequacy Methods. ESIG/G-PST Webinar Presentation. https://t.e2ma.net/click/csibkh/ki47uxb /odbh80
- Willis, R. (2020, August 13). Five Principles of Resource Adequacy for Modern Power Systems -ESIG. ESIG. https://www.esig.energy/five-principlesof-resource-adequacy-for-modern-power-systems/
- Comparison of capacity credit calculation methods for conventional power plants and wind power. (2009, May 1). IEEE Journals & Magazine | IEEE Xplore. https://ieeexplore.ieee.org/document/48061 29
- Madaeni, S., Sioshansi, R. & Denholm, P. (2012 July). Comparison of Capacity Value: Methods for Photovoltaics in the Western United States. Technical Report NREL/TP-6A20-54704 https:// www.nrel.gov/docs/fy12osti/54704.pdf
- Keane, A., Milligan, M., DAnnunzio, C., Dent, C.J., Dragoon, K., Hasche, B., Holttinen, H., Samaan, N., Soder, L., O'Malley, M. (2011). *Capacity Value of Wind Power*. IEEE Trans. Power Syst. (26:2), 2011; pp. 564–572.
- 36. Pelland, S., & Abboud, I. (2008). Comparing Photovoltaic Capacity Value Metrics: A case study for the City of Toronto. Progress in Photovoltaics:

Research and Applications, 16(8), 715–724. https:// doi.org/10.1002/pip.864

- Hoff, T.; Perez, R.; Ross, J.P.; Taylor, M. (2008). *Photovoltaic Capacity Valuation Methods*. SEPA REPORT # 02-08. Washington, DC: Solar Electric Power Association.
- Nova Scotia Power. (2014 April 3). Capacity Value of Wind Assumptions and Planning Reserve Margin. https://www.nspower.ca/docs/default-source/pdf-toupload/20140423-wind-capacity-value-assumption s.pdf?sfvrsn=2c12f8ab 0
- Wikipedia contributors. (2023c, September 24). List of hydroelectric power stations in Canada. Wikipedia. https://en.wikipedia.org/wiki/List_of_hydr oelectric_power_stations_in_Canada
- 40. Wikipedia contributors. (2023b, January 26). *List of generating stations in Manitoba.* Wikipedia. https://en.wikipedia.org/wiki/List_of_generating_stations_in Manitoba#Off-grid
- 41. Generating stations. (n.d.). https://www.hydro.mb. ca/corporate/facilities/generating_stations/
- 42. *About.* (n.d.). Energy.gov. https://www.energy.gov/ eere/geothermal/about
- Wikipedia contributors. (2024f, March 19). *Ring of fire.* Wikipedia. https://en.wikipedia.org/wiki/Ring_of __Fire
- 44. Enhanced geothermal systems. (n.d.). Energy.gov. https://www.energy.gov/eere/geothermal/enhancedgeothermal-systems
- 45. *Electricity generation.* (n.d.). Energy.gov. https:// www.energy.gov/eere/geothermal/electricity-generat ion
- 46. Hughes, J. (2023, August 22) Optimized CO2 Sequestration and Enhanced Geothermal System. Patent No. US11,732,929B2.
- 47. Bloomberg NEF. (2023, May 10). *Next-Generation* geothermal technologies are heating up. Bloomberg NEF. https://about.bnef.com/blog/next-generation-g eothermal-technologies-are-heating-up/
- Norbeck, J., & Latimer, T. M. (n.d.). Commercial-Scale demonstration of a First-of-a-Kind enhanced geothermal system. https://www.semanticscholar. org/paper/Commercial-Scale-Demonstration-of-a-Fi rst-of-a-Kind-Norbeck-Latimer/47d8751660affe73da 68d1f5a44edbdd14cc14e1#citing-papers
- Zatonski, V. & Brown, C., Eavor Technologies Inc. (2024a, January 11). *Eavor-Lite[™] update after four years of operation*. https://www.eavor.com/what-the-experts-say/eavor-lite-update-after-four-years-of-op eration/
- 50. Toews, Matthew D. R. (2020). Case Study of a *Multilateral Closed-Loop Geothermal System.* World Geothermal Congress. Reykjavik.
- 51. Government of Canada, Canada Energy Regulator. (2023, November 24). CER – Market Snapshot: Geothermal Power is stable and low carbon, but what is its potential in Canada? https://www.cer-

rec.gc.ca/en/data-analysis/energy-markets/market-s napshots/2023/market-snapshot-geothermal-powerstable-low-carbon-what-is-potential-canada.html

- 52. Belyakov, N. (2019). Geothermal energy. In Elsevier eBooks (pp. 475-500). https://doi.org/10.1016/b9 78-0-12-817012-0.00034-7
- 53. Van Zalk, J., & Behrens, P. (2018). The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S. Energy Policy, 123, 83-91. https://doi.org/10.1016/j.enpol.2018.08.023
- 54. Geothermal | Electricity | 2022 | ATB | NREL. (n.d.). https://atb.nrel.gov/electricity/2022/geothermal
- 55. Augustine, C., Sarah Fisher, Jonathan Ho, Ian Warren & Erik Witter. (2023 January). Enhanced Geothermal Shot Analysis for the Geothermal Technologies Office. Technical Report. NREL/TP-5700-84822. https://www.nrel.gov/docs/fy23osti/848 22.pdf
- 56. Augustine, C., Ho, J., & Blair, N. (2019), GeoVision Analysis Supporting Task Force Report: Electric

Sector Potential to Penetration. https://doi.org/10.21 72/1524768

- 57. Gallucci, M. (2023, November 28). America's first 'enhanced' geothermal plant just got up and running. Canary Media. https://www.canarymedia. com/articles/geothermal/americas-first-enhanced-g eothermal-plant-just-got-up-and-running?utm medi um=email
- 58. Trujillo, M. A. (2024, February 20). Eavor Technologies Secures Major Investment from Kajima for Geothermal Advancement. BNN. https:// bnnbreaking.com/tech/eavor-technologies-securesgame-changing-investment-from-kajima-corporation -to-advance-geothermal-energy
- 59. Government of Alberta, Canada. Geothermal Resource Development (2023). https://www.alberta. ca/geothermal-resource-development
- 60. Geothermal Resource Tenure Regulation Open government. (n.d.). https://open.alberta.ca/publica tions/2021 251

Appendix A: Electricity Futures by Province – Summary of the CER Findings (based on EF2023data [21])

Newfoundland and Labrador, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	12.5	12.6	12.8	12.9	13.1	13.2	13.3	13.3	13.4	13.5	13.5
Current Measures	12.3	12.4	12.5	12.5	12.6	12.7	12.7	12.8	12.8	12.9	13.0
Generation											
Canada Net-Zero	45.4	45.4	45.5	45.7	45.7	45.6	45.7	45.8	45.8	45.9	46.0
Current Measures	45.1	45.2	45.2	45.3	45.3	45.2	45.2	45.3	45.3	45.3	45.3
Interchanges											
Canada Net-Zero	32.3	32.2	32.1	32.1	31.9	31.7	31.7	31.6	31.5	31.4	31.3
Current Measures	32.6	32.6	32.5	32.6	32.4	32.3	32.3	32.2	32.2	32.2	32.2

Newfoundland and Labrador

Prince Edward Island

Prince Edward Island, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	1.9	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.4	2.4	2.5
Current Measures	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3
Generation											
Canada Net-Zero	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.7	1.7	1.8	2.3
Current Measures	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2.0	2.2
Interchanges											
Canada Net-Zero	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.7	-0.8	-0.8	-0.9	-0.4
Current Measures	-0.7	-0.7	-0.6	-0.6	-0.6	-0.5	-0.5	-0.4	-0.4	-0.4	-0.2

Nova Scotia, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	12.0	12.3	12.6	13.0	13.4	13.7	14.1	14.4	14.8	15.1	15.5
Current Measures	11.8	12.0	12.2	12.5	12.7	12.9	13.1	13.3	13.5	13.7	13.9
Generation											
Canada Net-Zero	7.8	9.6	11.7	13.0	13.9	14.1	15.8	17.6	19.1	20.4	21.7
Current Measures	7.8	8.4	9.1	9.4	9.5	9.5	9.6	9.9	10.0	10.0	10.1
Interchanges											
Canada Net-Zero	-5.0	-3.5	-1.8	-0.9	-0.4	-0.7	0.6	1.8	2.8	3.5	4.1
Current Measures	-4.7	-4.5	-4.0	-3.9	-4.0	-4.2	-4.4	-4.3	-4.4	-4.6	-4.6

Nova Scotia

New Brunswick

New Brunswick, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	15.7	15.8	16.0	16.3	16.6	16.8	17.0	17.2	17.5	17.7	18.0
Current Measures	15.3	15.5	15.6	15.8	16.0	16.2	16.4	16.5	16.7	16.9	17.1
Generation											
Canada Net-Zero	12.3	12.1	12.1	11.0	11.0	10.1	11.0	12.0	13.1	13.8	14.6
Current Measures	12.0	12.2	12.4	11.2	11.2	10.0	11.0	12.1	13.2	14.2	15.0
Interchanges											
Canada Net-Zero	-4.0	-4.3	-4.6	-6.1	-6.4	-7.6	-7.0	-6.4	-5.8	-5.4	-5.2
Current Measures	-4.3	-4.2	-4.2	-5.6	-5.9	-7.1	-6.3	-5.4	-4.4	-3.6	-3.0

				Qu	lebec						
Quebec, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	214.2	218.2	221.4	224.6	228.3	231.8	235.2	238.5	241.6	244.5	247.1
Current Measures	215.8	219.5	222.8	225.9	229.7	233.2	236.6	239.8	242.9	245.8	248.8
Generation											
Canada Net-Zero	234.7	243.7	250.4	257.3	261.9	266.9	270.8	273.1	275.3	277.6	283.9
Current Measures	235.6	244.2	250.7	257.8	262.3	268.9	271.2	274.1	277.6	281.8	285.3
Interchanges											
Canada Net-Zero	6.1	10.7	13.6	16.8	17.0	17.9	16.4	14.9	13.3	12.0	15.0
Current Measures	4.2	8.5	11.0	14.5	14.6	17.1	15.6	15.2	15.2	16.1	16.5

				0	Intario						
Ontario, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	155.8	161.6	168.0	174.6	182.6	190.1	198.3	207.2	216.7	226.3	235.5
Current Measures	156.0	159.8	164.0	167.9	172.7	176.9	181.0	185.1	189.4	193.7	198.4
Generation											
Canada Net-Zero	146.2	148.4	153.0	161.1	167.1	180.2	193.1	208.8	223.6	241.4	254.1
Current Measures	148.4	150.6	153.1	157.8	159.8	164.3	167.0	172.1	174.8	179.5	182.1
Interchanges											
Canada Net-Zero	-2.4	-6.3	-8.9	-8.8	-11.9	-9.1	-11.5	-10.3	-10.8	-8.8	-12.7

-5.9

-4.9

-6.2

-5.5

-7.2

-7.1

Current Measures

-0.5

-3.1

-4.5

-3.7

Year 2024

-9.2

Manitoba, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	24.2	24.7	25.4	26.1	26.9	27.6	28.4	29.2	30.1	31.0	31.8
Current Measures	24.3	24.7	25.1	25.6	26.1	26.6	27.0	27.4	27.9	28.3	28.7
Generation											
Canada Net-Zero	31.4	32.3	34.5	35.5	40.8	42.1	43.1	44.4	45.6	46.9	52.3
Current Measures	31.5	32.1	33.8	34.2	38.4	38.9	39.3	39.8	40.1	40.3	40.7
Interchanges											
Canada Net-Zero	11.3	11.6	14.5	14.6	18.5	18.6	18.3	18.2	18.0	17.6	21.7
Current Measures	11.3	11.5	14.3	14.2	17.5	17.5	17.4	17.4	17.2	17.0	16.9

Manitoba

Saskatchewan

Saskatchewan, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	26.1	26.9	27.7	28.5	29.4	30.3	31.3	32.4	33.7	35.1	36.4
Current Measures	27.0	27.6	28.1	28.4	29.0	29.4	29.9	30.3	30.7	31.2	31.7
Generation											
Canada Net-Zero	25.8	26.5	27.5	27.9	28.8	29.8	31.8	33.2	34.8	36.9	35.4
Current Measures	26.6	27.6	28.0	27.6	28.1	28.4	28.9	29.3	29.8	30.4	30.8
Interchanges											
Canada Net-Zero	-2.1	-2.1	-2.0	-2.3	-2.3	-2.2	-2.5	-2.6	-2.6	-2.3	-5.4
Current Measures	-2.2	-2.3	-2.3	-3.1	-3.2	-3.3	-3.3	-3.3	-3.3	-3.2	-3.2

Alberta, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	81.6	83.5	87.5	90.3	93.7	97.1	101.9	105.6	109.3	113.3	117.2
Current Measures	83.8	85.1	87.6	88.9	90.6	92.2	95.0	96.4	97.9	99.5	100.6
Generation											
Canada Net-Zero	90.4	92.4	96.1	100.0	103.4	106.8	112.9	116.5	119.3	122.3	128.5
Current Measures	93.0	95.3	98.3	101.3	103.8	105.7	108.3	109.5	110.8	112.0	112.4
Interchanges											
Canada Net-Zero	4.7	5.2	5.2	6.5	6.9	7.1	6.3	5.9	4.8	3.7	6.2
Current Measures	4.7	5.3	5.8	7.5	8.5	8.9	8.9	9.2	9.4	9.3	9.1

Alberta

British Columbia

British Columbia, TWh	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demand											
Canada Net-Zero	70.7	73.4	75.9	79.0	84.5	89.4	92.2	94.9	97.3	99.7	101.9
Current Measures	69.5	71.9	73.8	76.3	79.4	82.1	84.1	87.4	90.6	92.4	94.1
Generation											
Canada Net-Zero	72.7	73.6	74.9	75.9	80.4	84.3	88.9	92.1	95.3	98.8	96.0
Current Measures	72.4	73.4	74.1	74.8	77.0	78.8	80.9	83.9	86.4	88.2	89.6
Interchanges											
Canada Net-Zero	3.7	2.6	2.0	0.4	-0.1	-0.6	0.6	1.1	1.7	2.6	-2.5
Current Measures	-0.9	-2.2	-3.1	-4.6	-5.3	-5.9	-5.7	-5.9	-6.5	-6.3	-6.4

Appendix B: Electricity Generation Data by Fuel for Alberta, Saskatchewan, and Nova Scotia (based on Canada Future 2023 data)

Alberta

In NetZero scenario, wind power deployment will include 750 MW in 2025, 313 MW per year in 2026-2030, and very powerful 2285 MW per year deployment in 2031-2035. Solar power deployment will include 150 MW per year in 2026-2030, and 2216 MW per year in

2031-2035. Uranium SMR will be deployed at 91.8 MW per year in 2031-2035.

In Current Measures scenario, wind power deployment of 900 MW in 2028, and solar power deployment of 231 MW in 2026, and 400 MW per year

(2000 MW total) in 2031-2035. No Uranium SMR deployment expected.

Alberta		Canada NetZero			Current Measures	
Generation, TWh	2025	2030	2035	2025	2030	2035
Coal and Coke	0	0	0	0.00	0.00	0.00
Solar (Distributed)	0.33	0.76	1.51	0.28	0.45	0.83
Solar (Utility scale)	2.09	3.47	23.98	2.66	2.66	6.48
Onshore Wind	16.05	21.53	65.15	10.16	14.17	14.17
Hydro	1.65	1.65	1.35	1.65	1.65	1.65
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00
Bioenergy	1.41	1.60	1.04	1.59	1.19	0.86
Uranium SMR	0.00	0.00	3.20	0.00	0.00	0.00
Bioenergy with CCUS	0.00	0.00	5.74	0.00	0.00	0.00
Natural Gas	68.85	66.07	5.28	76.65	85.61	88.40
Natural Gas with CCUS	0.00	11.70	21.23	0.00	0.00	0.00
Oil	0.02	0.00	0.00	0.02	0.00	0.00
Total, including:	90.39	106.78	128.49	93.01	105.74	112.39
Clean Generation, TWh	20.12	39.11	122.17	14.75	18.93	23.13
Clean Generation, %	22.3%	36.6%	95.1%	15.9%	17.9%	20.6%
Non-Clean Generation, TWh	70.27	67.67	6.32	78.25	86.80	89.26
Non-Clean Generation, %	77.7%	63.4%	4.9%	84.1%	82.1%	79.4%

Saskatchewan

In NetZero scenario, wind power deployment expects a huge push of 1468 MW in 2024, 450MW in 2025, followed by 170 MW per year in 2026-2030, and 340 MW per year in 2031-2035. This is followed by solar power deployment: 20 MW in 2025, 32 MW in 2030, and then 270 MW per year in 2031-2035. Uranium SMR will be deployed at 214 MW per year from 2031 to 2035.

In Current Measures scenario, the same push of 1468 MW is indicated in 2024, 106 MW in 2025, 167 MW per year in 2026-2030, and 109 MW per year in 2031-2035 (209 MW in 2034). Solar power deployment will plan 32 MW in 2030, and 143 MW per year in 2031-2035

(53% of what is planned in NetZero). No Uranium SMR deployment expected.

Nova Scotia

In NetZero scenario, wind power will be deployed at 400 MW per year in 2026 to 2030, and then at 600 MW per year in 2031-2035.

In Current Measures scenario, wind power will increase annually by 38.5 MW per year from 2026 to 2030 and will continue growing: from 128.3 MW per year in 2031 to 122.5 MW per year in 2035.

No Uranium SMR deployment is expected in both scenarios.

Nova Scotia		Canada			Current	
Generation, TWh	2025	2030	2035	2025	2030	2035
Coal and Coke	3.34	0.00	0.00	3.34	0.00	0.00
Solar (Distributed)	0.00	0.01	0.02	0.00	0.01	0.01
Solar (Utility scale)	0.00	0.00	0.00	0.00	0.00	0.00
Offshore Wind	0.00	10.03	19.46	0.00	0.00	0.00
Onshore Wind	2.16	2.11	1.89	2.16	2.35	2.98
Hydro	0.98	0.87	0.23	0.98	0.99	0.99
Oil	0.00	0.00	0.00	1.23	5.82	5.67
Natural Gas	1.16	0.81	0.03	0.00	0.00	0.00
Bioenergy	0.15	0.27	0.04	0.10	0.33	0.36
Total, including:	7.79	14.10	21.66	7.81	9.49	10.01
Clean Generation, TWh	3.14	13.03	21.59	6.48	3.35	3.98
Clean Generation, %	40.3%	92.4%	99.7%	83.0%	35.2%	39.8%
Non-Clean Generation, TWh	4.65	1.07	0.07	1.33	6.15	6.03
Non-Clean Generation, %	59.7%	7.6%	0.3%	17.0%	64.8%	60.2%

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GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Comparative Characterization of Saltwater from Kula, Nembe, and Kwale in the Niger Delta, Nigeria

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GJRE-J Classification: LCC: QC809-945.35

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Comparative Characterization of Saltwater from Kula, Nembe, and Kwale in the Niger Delta, Nigeria

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Abstract- Three samples of water from Kwale, Nembe, and Kula in the Niger Delta were collected and characterized, and the following properties: pH, Temperature, Dissolved Oxygen, Turbidity, Acidity, Alkalinity, Electrical conductivity, Salinity, Oil and Grease, Total Hydrocarbon (THC), Heavy metals, BTEX and Poly Aromatic Hydrocarbon (PAH) were determined. The result of some of the key parameters showed that the Salinity of the Kula water sample is highest with a salt concentration of 13,115mg/L (at 30°C) followed by the Nembe water sample with a salt concentration of 2,500mg/L (at 29.68°C) and Kwale with a small salt concentration of 60mg/L (at 28.67°C). The electrical conductivity of the three water samples followed the same trend as salinity with Kula, Nembe, and Kwale water samples having electric conductivity of 20,101µS/cm (at 30°C), 1,489µS/cm (at 29.68°C), and 122µS/cm (at 28.67°C) respectively. The polyaromatic hydrocarbon content in the three water samples showed that the Nembe water sample has the highest polyaromatictric hydrocarbon of 0.969mg/L followed by the Kwale water sample with 0.705mg/L and Kula water sample with 0.229mg/L. Interestingly the results also showed that n-pentacosane concentration is the highest component of the Total Petroleum Hydrocarbon (TPH) in the Kula and Kwale samples while n-hexacosane concentration is the highest component of the TPH in the Nembe water sample. This explains why the Nembe water sample is cloudier than the Kwale and Kula water samples. But in BTEX composition the total BTEX is highest in Nembe water, followed by Kwale and the least of these components is in Kula water.

Keywords: characterization, seawater, physiochemical and heavy metal, polyaromatic hydrocarbon, total petroleum hydrocarbon, BTEX.

I. INTRODUCTION

Seawater, or salt water, is water from a sethe or ocean. On average, seawater in the world's oceans has a salinity of about 3.5% (35 g/L, 599

Author o: World Bank Africa Centre of Excellence, Oilfield Chemicals and Research, University of Port Harcourt, Rivers State, Nigeria. e-mail: godsdayusiabuulu@gmail.com mM). This means that every kilogram (roughly one litre by volume) of seawater has approximately 35 grams (1.2 oz) of dissolved salts (predominantly sodium (Na⁺) and chloride (Cl⁻) ions). The average density at the surface is 1.025 kg/L. Seawater is denser than fresh and pure water (density 1.0 kg/L at 4°C (39°F) because the dissolved salts increase the mass by a larger proportion than the volume. The freezing point of seawater decreases as salt concentration increases. At typical salinity, it freezes at about -2 °C (28°F) (Chester & Roy, 2012). The coldest seawater ever recorded (in a liquid state) was in 2010, in a stream under an Antarctic glacier, and measured -2.6°C (27.3°F). Seawater pH is typically limited to a range between 7.5 and 8.4. However, there is no universally accepted reference pH scale for seawater and the difference between measurements based on different reference scales may be up to 0.14 units (Chester & Roy, 2012).

Most of the seawater has a salinity of between 31 g/kg and 38 g/kg, which is 3.1-3.8%, seawater is not uniformly saline throughout the world. Where mixing occurs with fresh water runoff from river mouths, near melting glaciers, or vast amounts of precipitation (e.g. Monsoon), seawater can be substantially less saline. The most saline open sea is the Red Sea, where high rates of evaporation, low precipitation, low river run-off, and confined circulation result in unusually salty water. The salinity in isolated bodies of water can be considerably greater still - about ten times higher in the case of the Dead Sea. Historically, several salinity scales were used to approximate the absolute salinity of seawater. A popular scale was the "Practical Salinity Scale" where salinity was measured in "practical salinity" units (PSU)". The current standard for salinity is the "Reference Salinity" scale with the salinity expressed in units of "g/kg" (Corwin & Lesch, 2013).

The density of surface seawater ranges from about 1020 to 1029 kg/m³, depending on the temperature and salinity. At a temperature of 25°C, salinity of 35 g/kg, and 1 atm pressure, the density of seawater is 1023.6 kg/m³ (Feistel, 2008). Deep in the ocean, under high pressure, seawater can reach a density of 1050 kg/m³ or higher. The density of seawater also changes with salinity. Brines generated by seawater desalination plants can have salinities up to 120 g/kg. The density of typical seawater brine of 120 g/kg salinity

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at 25°C and atmospheric pressure is 1088 kg/m³ (Millero et al., 2008).

The pH of seawater is limited to the range of 7.5 to 8.4 while thermal conductivity is 0.6 W/mK at 25°C and a salinity of 35 g/kg. The thermal conductivity decreases with increasing salinity and increases with increasing temperature (Shargawy et al., 2010). Seawater contains more dissolved ions than all types of freshwaters (Millero et al., 2008). However, the ratios of solutes differ dramatically. For instance, although seawater contains about 2.8 times more bicarbonate than river water, the percentage of bicarbonate in seawater as a ratio of all dissolved ions is far lower than in river water. Bicarbonate ions constitute 48% of river water solutes but only 0.14% of seawater (Millero, et al., (2008). Differences like these are due to the varying residence times of seawater solutes; sodium and chloride have very long residence times, while calcium (vital for carbonate formation) tends to precipitate much more quickly. The most abundant dissolved ions in seawater are sodium, chloride, magnesium, sulfate, and calcium. Its osmolarity is about 1000m/l (Millero et al., 2008).

Small amounts of other substances are found, including amino acids at concentrations of up to 2 micrograms of nitrogen atoms per liter which are thought to have played a key role in the origin of life.

The composition of the total salt component is Cl^- (55%), Na^+ (30.6%), SO_2^- (7.7%), Mg^{2+} (3.7%), Ca^{2+} (1.2%), K^+ (1.1%), and Others (0.7%). Note that the unit of the above composition is in wt/wt, not wt/vol or vol/vol. Sea water elemental composition is given below.

The ocean has a long history of human waste disposal on the assumption that its vast size makes it capable of absorbing and diluting all noxious material (Larson & Carl-Fedrik 2021). While this may be true on a small scale, the large amounts of sewage routinely dumped have damaged many coastal ecosystems, and rendered them life-threatening. Pathogenic viruses and bacteria occur in such waters, such as *Escherichia coli*, *Vibrio cholerae* the cause of cholera, hepatitis A, hepatitis E, and polio, along with protozoans causing giardiasis and cryptosporidiosis. These pathogens are routinely present in the ballast water of large vessels, and are widely spread when the ballast is discharged (Larson & Carl-Fedrik 2021).

Nkoro River is in Rivers State in the Niger Delta area of Nigeria. The Salinity, dissolved oxygen, pH, and surface water temperature conditions of this River were studied for a period of one year (January – December 2008), and the following results were obtained (Abowei, 2009) The response of estuarine fishes to changes in salinity, dissolved oxygen, pH and surface water temperature conditions does not only enhance our biological understanding of estuarine fish but contributes to the understanding of the potential effects of anthropogenic impacts on estuarine fish species. Dissolved oxygen meter of the model: Oxy-Guard Handy MK II was used in measuring dissolved oxygen and temperature. pH was measured using a pH meter (model: Hanna Instrument model No. H1 8915 ATC) while salinity was measured using a saline meter, model: New S-100. for each of the parameters. The probe end of the meter was dipped into the river while the value at the pointer of the scale was read off and recorded. The measurements were taken while inside the canoe along Nkontoru - Job Ama, which is part of the Nkoro river system. Dissolved oxygen (DO) was measured in milligrams per liter (mg/l); temperature in °C (degrees centigrade); and salinity in parts per thousand (ppt). Salinity values ranged from 5% (September) to 17% (February and March). Dissolved Oxygen values ranged from 6mg/l (January, April, July, and October) to 10mg/l (September). pH values ranged from 6.1(August) to 8.5 (November) and Temperature values ranged from 24.0°C (July) to 32.0°C (March).

Salinity values ranged from 12.8±0.30 (%) (Station 4) to 13.3±0.10 (%) (Station 3). Dissolved Oxygen values ranged from 3.2 ± 0.1 mg/l (Station 3) to 7.3±0.16 mg/l (Station 1). pH values ranged from 7.3±0.17 (Station 1) to 7.7±0.14 (Station 3) and Temperature values ranged from 27.3 ± 0.24 (Station 1) to 33.7±0.21 (Station 3). There was no significant difference in salinity and pH between stations, but dissolved oxygen, and temperature showed significant differences between stations (P#0.05). The results of the correlation matrix analysis showed a significant correlation between the variables at different stations. The association between the environmental variables in the Nkoro River was generally similar because the water at the stations was seemingly from the same source, the Atlantic Ocean through the Bonny River. A positive association was observed indicating functional similarity. The varying magnitude of the relationship between the water variables in the lower Bonny River of the Niger Delta was attributed to the micro habit difference study of Salinity, Dissolved Oxygen, PH, and surface temperature conditions in the Nkoro River the of Niger Delta.

The study area for this research is Kwale, Nembe, and Kula Rivers.

a) KWALE

Kwale is the most populous community of the Uwkuani-speaking people of Delta State, Nigeria, and is located within the colonial Warri province (FRN, 2006). Kwale is generally considered a city especially considering its oil and gas reserves which can be utilized to transform the town and neighboring communities into a modern city (Mart Oil Resources Launches New Brand Identity, 2018). Kwale is host to oil and gas companies, some of which have a presence in different parts of the African city such as a gas flow facility which is situated at Ebedei nearby the Umukwuta area, and another at Ebendo and Umusadege with a pipeline running from Aboh and river Ase creek (TheNation, 2018). The location of the Kwale city in the Nigerian map is shown in fig 1.



Fig. 1: Location of Kwale on the Nigerian map. (Ukwuani, 2021)

b) NEMBE

Nembe is the headquarters of the Nembe Local of Bayelsa State in Government Nigeria. lts geographical coordinates are 4° 32'23" North, 6° 24' East (The Bayelsa State Oil & Environmental Commission, 2022). It is a low-lying coastal area in the mangrove swamp rural area of the Niger Delta. The Nembe kingdom hosts international oil and gas companies like SPDC and ENI Nigeria. The presence of these companies has given rights to a lot of oil exploration and exploitation activities (NLGA, 2021). They also lamented years of oil spillages that have destroyed their environment, aquatic life, as well as air and water pollution and called on the Bayelsa State Oil and Environmental Commission (BSOEC) and international communities to come to their rescue (The Guardian Nigeria News, 2019). The location of the Nembe city in the Nigerian map is shown in fig. 2.



Fig. 2: Location of Nembe on the Nigerian map. (NAD, 2022)

c) KULA

The Kula tribe of the Ijaw people lives in Akuku Toru Local Government Area, southwestern Rivers State, Nigeria (Talbot, 1932). The Kula people did not originally speak Kalabarias their language but have lost their real language due to trade and close interactions with the small Kalabari-speaking tribe Kalabari. The is sometimes classified as a Kalabari community rather than its tribe (Alagoa, 2001). The tribe seat is the town of Kula (also known as Anyame-Kula or Anyaminama-Kula) founded and established by King Sara. Kula is situated in the southwestern axis of Rivers State of Nigeria under the Akuku - Toru Local Government Area of Rivers State (Alagoa, 1971). Its geographical coordinates are 4° 20' 29' North and 6° 38' 46" East. It is a low-lying coastal area in the mangrove swamp region of the Niger Delta, with a few feet above the mean sea level, located very close to the Atlantic Ocean (Alagoa, 1964). The location of the Kula city in the Nigerian map is shown in Fig. 3.



Fig. 3: Location of Kula in the Nigerian map. (Pacheco Pereira, 1505–1520)

research This aims to compare the characteristics of the saltwater in Kwale. Kula. and Nembe water which would form the framework for further research work by scholars on the one hand and enable the marine and construction industry to take the correct decision from the design and conceptual stage of marine projects to be sited as well as marine vessels and equipment to be used in this region in particular and the Niger Delta in general.

II. MATERIALS AND METHOD

a) Sample Collection

Saltwater samples were collected from the Rivers in Nembe (Bayelsa), Kula (Rivers), and Kwale

(Delta) as follows. Water sampling bottles were thoroughly washed and dried. The sampling bottles were then dipped into the seawater at sampling points to collect the required volume of the water sample. Three samples have been collected from each area (Nembe, Kula, and Kwale).

Characterization of Salt Water Samples b)

The standard methods below were used to characterize the saltwater samples to determine the presence and composition of the marine saltwater components that were relevant to the study and listed in Table 1.

S/N	Parameters	Standard Method
1	рН	APHA 4500A
2	Temperature	APHA 4500A
3	Dissolved oxygen (DO)	APHA 4500-0
4	Turbidity	APHA 5.0NTU
5	Acidity	APHA 2310B
6	Alkalinity	APHA 2320B
7	Electrical conductivity	APHA 2510 B
8	Salinity	ASTM D6529
9	Oil & grease	EPA 418.1/413.2
10	Total hydrocarbon content (THC)	EPA 418.1/413.2
11	Heavy metals	AAS UNICAMM 939
12	BTEX	ASTM D3328
13	PAH	ASTM D 3328-78

Table 1: Standard Parameters for the Characterization of Salt Water Samples

Source: APHA 2013

III. Results and Discussions

The results of the physiochemical and heavy metal characterization of the salt water samples are stated in Table 2, Table 3, Table 4, and Figure 5. The results in Table 2 showed that the salinity of the Kula water sample is highest with a salt concentration of 13,115mg/L (at 30° C) followed by the Nembe water sample with a salt concentration of 2,500mg/L (at 29.68°C) and Kwale with a little salt concentration of 60mg/L (at 28.67°C).

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Table 2: Dhysicshomical and box	w motal obaractorization	n at calt water comple	(Dh	voioohomiotr	1 and hoave	(motolo)
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S/N	Parameters	Method	Kwale	Nembe	Kula	Dpr Limits	Fmenv Limits
1	рН	APHA 4500-HB	7.68	7.37	7.26	6.5-8.5	6.5-8.5
2	Temperature (°C)	APHA 2550B	28.67	29.68	30.01	30	35
3	$EC(\mu/cm)$	APHA 2510B	122	1489	20101		
4	Salinity (Mg/L)	APHA 25208	60	2,500	13,115	-	2000
5	DO(Mg/L)	APHA 4500OC	5.14	4.49	4.85	10.50	
6	Turbidity (NTU)	APHA 2130C	10.00	35.50	25.50	10	
7	Alkalinity (Mg/L)	APHA 2320B	41.00	35.00	51.00		
8	Acidity (Mg/L)	APHA 2310B	9.00	0.50	11.00		
9	(THC) (Mg/L)	API 45 & EPA 4184/4132	0.114	0.410	0.727		
10	As (Mg/L)	APHA 3111C	< 0.011	< 0.011	0.030		
11	Cd (Mg/L)	APHA 3111C	0.009	0.114	0.681	-	0.5
12	Ni (Mg/L)	APHA 3111C	0.021	0.087	0.059		
13	Fe (Mg/L)	APHA 3111C	2.072	4.424	10.099	1	
14	Zn (Mg/L)	APHA 3111C	1.126	2.575	6.037	01	0.02
15	Hg (Mg/L)	APHA 3111D	< 0.015	<0.015	< 0.015	01	
16	Ba (Mg/L)	APHA 3111D	< 0.013	0.078	0.145		
17	V (Mg/L)	APHA 3111D	< 0.019	<0.019	< 0.019		

Expectedly and as shown in Table 2 the electric conductivity of the three water samples followed the same trend as the salinity with Kula, Nembe, and Kwale water samples having electric conductivity of 20,101 µS/cm (at 30°C), 1,489 µS/cm (at 29.68°C), and 122 μ S/cm (at 28.67°C) respectively. This is because the more saline water body contains more quantity of ions that help to conduct charges in the water hence soluble salts are usually added to water to improve the electrical conductivity of the water often used as electrolyte. This is consistent with the work by Fedorov (2002) who established that the salinity of seawater is proportional to the conductivity of the water. The iron content in the three water samples was observed to also follow a similar trend with the Kula water sample having an Iron concentration of 10.099mg/L while Nembe and Kwale water samples had an Iron concentration of 4.424mg/L and 2.072mg/L respectively.

The Polyaromatic hydrocarbon content in the three water samples is shown in Table 3. The result

showed that the Nembe water sample has the highest polyaromatic hydrocarbon of 0.969mg/L (with traces of pyrene) followed by the Kwale water sample with 0.705mg/L (with traces of acenaphthylene, phenanthrene, anthracene, and fluoranthene) and the Kula water sample with 0.229mg/L polyaromatic hydrocarbon (with traces of pyrene). One of the main differences in the areas of saltwater is that Kwale water is richer pyrene than those of Nembe and Kula and the inverse is noticed for acenaphthylene, phenanthrene, anthracene, and fluoranthene components.

S/N	Parameters (PAH Components (mg/L))	Methods	Kwale	Nembe	Kalu
1.	Naphthalene	EPA 8100	0.006	0.002	< 0.001
2.	Acenapthene	EPA 8100	0.004	0.033	0.065
3.	Acenaphthylene	EPA 8100	< 0.001	0.013	< 0.001
4.	Fluorine	EPA 8100	0.010	0.008	0.012
5.	Phenanthrene	EPA 8100	< 0.001	0.011	0.013
6.	Anthracene	EPA 8100	< 0.001	0.006	0.006
7.	Fluroanthene	EPA 8100	< 0.001	0.012	0.008
8.	Pyrene	EPA 8100	0.018	< 0.001	< 0.001
9.	Benz (a) anthracene	EPA 8100	0.023	0. 029	0.006
10.	Chrysene	EPA 8100	0.028	0.010	0.008
11.	Benzon (b) fluoranthene	EPA 8100	0.044	0. 108	< 0.001
12.	Benzo (k) fluoranthene	EPA 8100	0.030	0.038	0.010
13.	Benzo (a) pyrene	EPA 8100	0.031	0. 103	0.022
14.	Indeno (1,2,3-c,d) pryene	EPA 8100	0.179	0.168	0.023
15.	Dibenz (a,h) anthracene	EPA 8100	0.170	0.172	0.025
16.	Benzon (g,h,i) perylene	EPA 8100	0.162	0.250	0.024
	Total (Mg/L)		0.705	0.964	0.229

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Table 4 shows the total petroleum hydrocarbon concentration in each of the three water samples. The result showed that the Kula water sample has the highest total petroleum hydrocarbon giving 5.450mg/L (with traces of C8-C12), followed by the Nembe water with a total petroleum hydrocarbon sample concentration of 3.626mg/L (with traces of C8-C11) and the Kwale water sample with a TPH of 1.001mg/L (with traces of C8-C13, C15, C17 and pristine). This is consistent with the initial total hydrocarbon result of 7.27mg/L, 4.10mg/L, and 1.14mg/L for Kula, Nembe, and Kwale water samples respectively as stated in Table 4.

S/N	Parameters Aliphatic Components (Mg/L)	Methods EPA 3510C	Kwale	Nembe	Kula
1	n-Octane (C8)	EPA 3510C	< 0.001	< 0.001	< 0.001
2	n-Nonane (C9)	EPA 3510C	< 0.001	< 0.001	< 0.001
3	n-Decane (C10)	EPA 3510C	< 0.001	< 0.001	< 0.001
4	n-Undecane (C11)	EPA 3510C	< 0.001	< 0.001	< 0.001
5	n-Dodecane (C12)	EPA 3510C	< 0.001	0.001	< 0.00
6	n-Tridecane (C13)	EPA 3510C	< 0.001	0.001	0.007
7	n-Tetradecane (C14)	EPA 3510C	0.005	0.002	0.004
8	n-Pentadecane (C15)	EPA 3510C	< 0.001	0.006	0.006
9	n-Hexadecane (C16)	EPA 3510C	0.009	0.002	0.004
10	n-Heptadecane (C17)	EPA 3510C	< 0.001	0.002	0.006
11	Pristine	EPA 3510C	< 0.001	0.009	0.009
12	n-Octadecane (C18)	EPA 3510C	0.005	0.003	0.006
13	Phytane	EPA 3510C	0.008	0.010	0.022
14	n-Nonadecane (C19)	EPA 3510C	0.009	0.004	0.012
15	n-Eicosane (C20)	EPA 3510C	0.007	0.002	0.005
16	n-Henelcosane (C21)	EPA 3510C	0.011	0.009	0.022
17	n-Docosane (C22)	EPA 3510C	0.011	0.030	0.071
18	n-Tricisane (C23)	EPA 3510C	0.010	0.047	0.110
19	n-Tetracosane (C24)	EPA 3510C	0.015	0.074	0.218
20	n-Pentacosane (C25)	EPA 3510C	0.196	0.139	0.502
21	n-Hexacosane (C26)	EPA 3510C	0.173	0.077	0.421
22	n-Heptacosane (C27)	EPA 3510C	0.031	0.108	0.410
23	n-Octacosane (C28)	EPA 3510C	0.019	0.246	0.426
24	n-Nonacosane (C29)	EPA 3510C	0.061	0.226	0.450
25	n-Triacontane (C30)	EPA 3510C	0.028	0.397	0.710
26	n-Hentriacontane(C31)	EPA 3510C	0.106	0.302	0.505
27	n-Dotriacontane (C32)	EPA 3510C	0.052	0.197	0.501
28	n-Tritracontane (C33)	EPA 3510C	0.015	0.117	0.246
29	n-Tetratriacontane (C34)	EPA 3510C	0.034	0.235	0.217
30	n-Pentatriacontane (C35)	EPA 3510C	0.023	0.729	0.254
31	n-Hexatriacontane (C36)	EPA 3510C	0.021	0.377	0.150
32	n-Heptatriacontane (C37)	EPA 3510C	0.021	0.191	0.296
33	n-Octatriacontane (C38)	EPA 3510C	0.037	0.031	0.198
34	n-Nonatriacontane (C.39)	EPA 3510C	0.025	0.062	0.062
35	n-Tetracontane (C40)	EPA 35100	0.028	0.052	0.048
00	Total TPH (Mg/L)	217100100	1 001	3.662	5 450

Table 4: Total Petroleum Hydrocarbon, TPH characterization of salts water sample

The above result also showed that npentacosane concentration is the highest component of the TPH in the Kula and Kwale water sample while nhexacosane concentration is the highest component of the TPH in the Nembe water sample. This explains why the Nembe water sample is cloudier than the Kwale and Kula water samples.

Table 5 shows the BTEX composition of the three water samples. The result showed that Benzene and Xylene concentrations were highest in the Nembe water sample and lowest in the Kula water sample while the Ethylbenzene concentration was highest in Kwale than Nembe water sample.

S/N	Parameters	Methods	Kwale	Nembe	Kalu
	BTEX Components	EPA 8021			
1.	Benzene	EPA 8021	0.14	0.37	0.06
2.	Toluene	EPA 8021	< 0.01	0.09	0.04
З.	Ethylbenzene	EPA 8021	0.11	0.04	< 0.01
4.	(m, p, o)-Xylene	EPA 8021	0.15	0.19	0.08
	Total BTEX (Mg/L)		0.40	0.69	0.18





Fig. 4: Initial concentration of the major hydrocarbon family and heavy metal in Kwale, Nembe, and Kula water Samples

Figure 4 is a column chart showing the result summary of the initial composition of the major hydrocarbon family and heavy metal in the three different water samples. The result showed that the aliphatic and poly aromatic hydrocarbon composition in the water samples is highest in Nembe water followed by Kula water while Kwale has the least of these components. But in BTEX composition the total BTEX is highest in Nembe water, followed by Kwale and the least of these components is in Kula water.

IV. CONCLUSION

main the The parameters used in characterization of Kwale, Nembe, and Kula water bodies are Salinity, electric conductivity, polyaromatic hydrocarbon, and BTEX have shown that these parameters showed that the three water bodies are significantly different from one another even though they are all part of the Niger Delta. The salinity value for Kula River which is closest to the Atlantic Ocean and takes its source from the Atlantic Ocean was shown to have the highest (13,115mg/l at 30°C) followed by Nembe (2,500mg/l at 29.68°C) water body and the least salinity value is from Kwale water body (60mg/l at 28.67°C). This is expected because the closer you are to the ocean the higher its salinity value. Kwale is fresh water with very

little salinity value as it is the most distant from the Atlantic Ocean among the three water bodies. The electric conductivity of the three water samples is also consistent with the salinity trend with Kula, Nembe, and Kwale water samples having electric conductivity of 20,101µS/cm (at 30°C), 1,489µS/cm (at 29.68°C), and 122µS/CM (at 28.67°C) respectively. This is expected because electric conductivity is a function of the availability of ions in water which is proportional to the salinity of water. Based on this result corrosion is relatively expected to be highest around the Kula area more than the other two marine environments if all other factors that can cause corrosion remain the same. On the other hand, Kula could be the preferred environment to site a salt-producing industry. The Total Hydrocarbon (THC) content in the Kula water sample is the highest (0.727mg/l) followed by Nembe (0.411mg/l) and the least for the Kwale water sample. This may be due to increased oil spill and bunkering activities in the Kula environment with a lot of crude oil production activities followed by Nembe and then Kwale. Among the three the various hydrocarbon water bodies familv composition of the three water bodies showed that Polyaromatic hydrocarbon in the Nembe water sample has the highest value of 0.969mg/l (with traces of pyrene) followed by the Kwale water sample with

0.705mg/l (with traces acenaphthylene, of phenanthrene, anthracene and fluoranthene) and Kula water sample with 0.229mg/l (with traces of pyrene). Interestingly the results also showed that n-pentacosane concentration is the highest component of the Total Petroleum Hydrocarbon (TPH) family in the Kula and Kwale water samples while n-hexacosane concentration is the highest component of the TPH in the Nembe water sample. This explains why the Nembe water sample is cloudier than the Kwale and Kula water samples. Finally, in BTEX composition, the total BTEX is highest in Nembe water, followed by Kwale and the least of these components is in Kula water.

References Références Referencias

- 1. "Delta to build three modular refineries". The Nation. February 22, 2018. Retrieved April 21, 2018.
- "Federal Republic of Nigeria: 2006 Population Census" (PDF). Archived from the original (PDF) on 5 March 2012. Retrieved 25 July 2016.
- "Mart oil resources launches new brand identity". This Day. March 23, 2018. Retrieved April 21, 2018. https://en.wikipedia.org/wiki/Kwale,_Nigeria
- 4. "Nembe Local Government Area". www.manpower. com.ng Retrieved 2021-09-12.
- 5. "Nigeria: Administrative Division (States and Local Government Areas) - Population Statistics, Charts, and Map". www.citypopulation.de. Retrieved 2022-03-11.
- "Oil Spill: Bayelsa communities slam oil firms over neglect". The Guardian Nigeria News - Nigeria and World News. 2019-07-13. Retrieved 2021-09-18.
- 7. "The Bayelsa State Oil & Environmental Commission". The Bayelsa State Oil & Environmental Commission. Retrieved 2022-03-10.
- 8. "Ukwuani: An ethnic people and language". 26 November 2021.
- 9. Fedorov, K (2018) Formula for converting the electrical conductivity of seawater into salinity with digital temperature salinity probe under average ocean conditions *Oceanology* 11, 622-626.
- APHA 2013, Standard Parameters for the Characterization of Saltwater Samples. https://aca demicjournals.org/journal/AJEST/article-full-text-pdf/ C71880855964
- 11. Feistel, R. (2008). A Gibbs function for Seawater Thermodynamics from -6 to 80°C and Salinity up to 120 g kg-1, *Deep-Sea Part I*, 55 (12), 1639–1671.
- 12. Larson J. D. G & Carl-Fredrik F. (2021). Antibiotics Resistance in the Environment *Nature Reviews Microbiology* 20, 257-269.
- Millero, F. J., Feistel, R. & Write, D. G. (2008). The Composition of Standard Sea Water and the Definition of Reference Composition Salinity Scale Deep Sea Research Part I Oceanographic Research Papers, 55(1), 50-72.

- 14. Pacheco P. (1505–1520). Esmeralda De Situ Orbis. London, Printed for the Hakluyt Society.
- Shargawy, M. H., Lienhard V., John, H. & Zubaer, S. M. (2010). The Thermo-Physical Properties of Sea Water. A review of Existing Correlations and Data. 16, 354-380.
- 16. Talbot, P. A. (1932). Tribes of the Niger Delta, London's.

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GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Models and Algorithms for the Diagnosis of Parkinson's Disease and their Realization on the Internet of Things Network

By Uladzimir, Vishniakou & Yiwei, Xia

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Abstract- This article aims to investigate an innovative approach utilizing model, algorithms and IoT technology for early Parkinson's disease detection. It introduces the comprehensive IoT network that has the IoT platform, enabling the collection of voice data via mobile phones, extraction of relevant features and data processing. Within this process, a Fully Connected Neural Network (FCNN) model is employed to calculate the probability of Parkinson's disease, potentially providing healthcare professionals and patients with a convenient, accurate, and early diagnostic tool. The study delves into the structure, algorithms, and the integral role of the FCNN within the IoT network, emphasizing its potential impact on the healthcare sector.

Keywords: parkinson's disease, IoT technology, early detection, voice data, noise reduction, fully connected neural network, IT-diagnosis.

GJRE-J Classification: LCC: RC382

MODE LSAN DA LGOR I THMSFORTHE DI AGNOSI SOFPARK I NSONS DI SEASE AND THE I RREALIZATI ONON THE I NTERNE TOFTHI NGSNETWORK

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Models and Algorithms for the Diagnosis of Parkinson's Disease and their Realization on the Internet of Things Network

Uladzimir, Vishniakou ^a & Yiwei, Xia ^o

Abstract- This article aims to investigate an innovative approach utilizing model, algorithms and IoT technology for early Parkinson's disease detection. It introduces the comprehensive IoT network that has the IoT platform, enabling the collection of voice data via mobile phones, extraction of relevant features and data processing. Within this process, a Fully Connected Neural Network (FCNN) model is employed to calculate the probability of Parkinson's disease, potentially providing healthcare professionals and patients with a convenient, accurate, and early diagnostic tool. The study delves into the structure, algorithms, and the integral role of the FCNN within the IoT network, emphasizing its potential impact on the healthcare sector.

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I. INTRODUCTION

s society continues to evolve and science and technology advance, there is an increasing emphasis on early detection and diagnosis of health issues. Parkinson's disease, as a chronic neurological condition, profoundly impacts the quality of life for affected individuals. Early diagnosis is crucial in providing more effective treatment and care [1]. This paper focuses on exploring a novel approach using IoT technology for early detection of Parkinson's disease [2]. Authors [3] proposed approach to early Parkinson's disease detection on voice analythis base. We will introduce a comprehensive IoT network that collects voice data through mobile phones, extracts relevant features, facilitates data transmission and processing, and ultimately outputs the probability of Parkinson's disease. The implementation of this method holds the promise of providing a more convenient, accurate, and early diagnostic tool for both medical professionals and patients. In this paper, we will delve into the structure and algorithms of this IoT network and discuss its potential impact in the field of healthcare. It is our hope that this innovative approach will be a significant step forward in early intervention and treatment of Parkinson's disease.

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Initially, voice data is collected and preprocessed using a mobile phone. This involves capturing speech data from Parkinson's disease (PD) patients for a duration of 5 seconds at a sampling frequency of 44.1 kHz. To enhance signal quality, the spectral subtraction algorithm [4] is employed to eliminate ambient noise.

Subsequently, features are extracted from the pre-processed speech data after noise reduction. The data is then transmitted to the voice channel an IoT platform. The data is fed into a Matlab analysis function.

The Matlab analysis module plays a pivotal role in interpreting the data by loading a 3-layer FCNN model deployed in the cloud. It processes the data and generates a probability value indicating the likelihood of a possible Parkinson's disease diagnosis.

Finally, the results are relayed from the IoT platform to a mobile phone and the outcomes are displayed on a screen for further examination and evaluation.

II. DATA COLLECTION AND PRE-PROCESSING

Use the spectrum subtraction algorithm for the voice data, the specific process is as follows:

1. Split the original sound signal into frames, the length of each frame is 256 samples, using 50% overlap to split the frames and get a series of frames of signal.

Let the original sound signal be denoted as s[n], where *n* is the sample index. - Let the frame length be L = 256 samples and the overlap percentage be 50%.

Define the frame index k such that the start index of the k-th frame is given by:

$$n_k = (k-1) * \frac{L}{2}, k = 1,2,3$$
 (1)

The k-th frame of the signal is then given by:

$$s_k[n] = s[n_k + n_{k+1}], 0 \le n < L$$
 (2)

2. Perform Fourier transform on each frame of signal to get the corresponding spectrum.

Let $s_k[n]$ be the k-th frame of the signal. Apply a window function w[n] to the frame to reduce spectral leakage, such as a Hamming window.

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Compute the Fourier transform of the windowed frame to get the complex spectrum $X_k[f]$:

$$X_{k}[f] = sum\left(w[n] * s_{k}[n] * exp\left(-j * 2 * pi * f * \frac{n}{L}\right)\right), 0 <= f <= \frac{L}{2}$$
(3)

1

Use spectral subtraction algorithm $X_{avg}[f]$ as the basis to calculate the noise spectrum.

3. Wiener filter the noise spectrum to obtain a more accurate noise estimate.

Let $X_{noise}[f]$ be the noise spectrum estimated from $X_{ava}[f]$.

Apply a Wiener filter to $X_{noise}[f]$ to obtain a more accurate estimate:

$$X_{noise}^{filtered} [f] = \frac{X_{noise} [f]}{(X_{noise} [f] + \alpha * X_S[f])}$$
(4)

where α is a smoothing parameter and $X_s[f]$ is the spectrum of the original signal.

 Compare the spectrum of each frame with the Wiener filtered noise spectrum, calculate the signalto-noise ratio and consider the frequency components with a signal-to-noise ratio lower than 10 dB as noise components [5].

Let $X_k[f]$ be the complex spectrum of the k-th frame of the signal.

Compute the signal-to-noise ratio (SNR) for each frequency component as:

$$SNR[f] = 10 * log10 \left(\frac{|X_k[f]|^2}{|X_{filtered} [f]|^2} \right)$$
(5)

 $\label{eq:consider} \begin{array}{l} \mbox{Consider the frequency components with SNR} \\ < 10 \mbox{ dB as noise components.} \end{array}$

5. Subtract the noise frequency components by adjusting the coefficient to 0.5 to obtain the noise removed spectrum.

Let be the noiseless spectrum of the k-th frame of the signal.

For each frequency component f, if SNR[f] < 10 dB, then set the magnitude of $X_k^{noiseless}[f]$ to:

$$\left|X_{k}^{noiseless}\left[f\right]\right| = 0.5 * \left|X_{k}\left[f\right] - X_{noise}^{filtered}\left[f\right]\right| \quad (6)$$

To obtain the complete signal after removing noise, we need to convert the noise-removed spectrum back to the time domain and superimpose each frame.

Let $X_k^{noiseless}$ [f] be the noiseless signal in the frequency domain of the k-th frame of the signal, and $X_k^{noiseless}$ [n] be the corresponding signal in the time domain. Similarly, let Y_k [f] be the noise-removed spectrum of the k-th frame, and Y_k [n] be the corresponding signal in the time domain.

To convert the noise-removed spectrum back to the time domain, we can apply the inverse Fourier transform to $Y_k[f]$, which gives us $Y_k[n]$:

$$Y_k[n] = IFFT(Y_k[f])$$
(7)

Then, we can combine the noise-removed signal of each frame to obtain the complete signal without noise:

$$x_{noiseless}[n] = sum_k (x_k^{noiseless}[n] * w_k[n])$$
(8)

where $w_k[n]$ is a window function applied to each frame, and the sum is taken over all frames.

The Figure 1 shows the algorithms of data preprocessing.



Figure 1: Algorithms of data pre-processing

The voice data after removing the noise is windowed. The main advantage of using the Hamming window [6] to extract the signal window is that it can reduce the oscillation effect at the edge of the window while retaining the main components of the signal inside the window. The window size is 1024 and the frequency of the voice data is 44.1 khz. The frequency of the voice data is 44.1 khz and the overlap rate of the window is 50%, so the speech time of a window is about 23 ms.

Let x[n] be the original signal in the time domain with a sampling frequency of $fs = 44.1 \ kHz$. Let w[n] be the Hamming window of size N = 1024.

The windowed signal $x_w[n]$ is obtained by multiplying x[n] with the window w[n] and shifting the window by a hop size of $H = \frac{N}{2}$:

$$x_w[n] = x[n] * w[n - n_0]$$
(9)

where $n_0 = k * H$ for some integer k.

The Hamming window w[n] is defined as:

$$w[n] = 0.54 - 0.46 * \cos\left(2 * pi * \frac{n}{N-1}\right), 0 \le n \le N-1$$
(10)

The duration of each windowed segment is $T = \frac{N}{fs} = \frac{1024}{44100}$, $s = 0.023 \sec(23 ms)$, and the overlap between adjacent segments is $\frac{H}{r} = 2$.

III. FEATURE EXTRACTION

Feature extraction of the voice data [7] is performed within the specified window, as illustrated in Table 1 below.

Table 1: Extraction of all featur	es
-----------------------------------	----

nNum	Feature Name	Description
1	MDVP:Fo(Hz)	Average vocal fundamental frequency
2	MDVP:Fhi(Hz)	Maximum vocal fundamental frequency
3	MDVP:Flo(Hz)	Minimum vocal fundamental frequency
4	MDVP:Jitter(%)	Measure of variation in fundamental frequency (percentage)
5	MDVP:Jitter(Abs)	Measure of variation in fundamental frequency (absolute value)
6	MDVP:RAP	Measure of variation in fundamental frequency (relative amplitude perturbation)
7	MDVP:PPQ	Measure of variation in fundamental frequency (pitch period perturbation quotient)
0	litter: DDB	Measure of variation in fundamental frequency (average of absolute differences of
0	JILLEI .DDF	differences between adjacent periods)
9	MDVP:Shimmer	Measure of variation in amplitude (local variation in amplitude)
10	MDVP:Shimmer(dB)	Measure of variation in amplitude (local variation in amplitude in dB)
11	Shimmer:APQ3	Measure of variation in amplitude (amplitude perturbation quotient, 3-point method)
12	Shimmer:APQ5	Measure of variation in amplitude (amplitude perturbation quotient, 5-point method)
13	MDVP:APQ	Measure of variation in amplitude (average amplitude perturbation quotient)
14	Shimmer:DDA	Measure of variation in amplitude (average absolute difference of amplitudes
		between consecutive periods)
15	NHR	Ratio of noise to tonal components in the voice
16	HNR	Ratio of harmonics to noise in the voice
17	RPDE	Nonlinear dynamical complexity measure
18	D2	Nonlinear dynamical complexity measure
19	DFA	Signal fractal scaling exponent
20	spread1	Nonlinear measure of fundamental frequency variation
21	spread2	Nonlinear measure of fundamental frequency variation
22	PPE	Nonlinear measure of fundamental frequency variation

IV. DATA TRANSMISSION AND PROCESSING

To upload the 22 features to Thingspeak [8] IoT for analysis.

1. Creating a Channel. Figure 2 below shows the setup of the VOICE channel.

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Percentage complete	30%	
Channel ID	2045599	
Name	voice	
Description		/
Field 1	featurel	
Field 2	feature2	
Field 3	feature3	
Field 4	feature4	
Field 5	feature5	
Field 6	feature6	
Field 7	feature7	
Field 8	feature8	



Getting the voice channel write/read API key and channel ID. The figure 3 below shows the voice channel 2. write/read API key and channel ID.

Channel ID; 2045599 Author: mwa0000029 Access: Public	248662			
Private View Pu	blic View	Channel Settings	Sharing	API Keys
Write API	Key			
Key	RT2VJK	2XDGSU4G7U		
	Generat	e New Write API Key		
Read API	Keys			
Key	Y7TRGS	2U54UWG92P		
Note				,
			1.15	
	Save No	te Delete API	KOY	

Figure 3: The write/read API key and channel ID of the voice channel

Useing the API in the phone. The API library code uses the HTTP protocol to upload 22 voice features to the З. voice channel. The Figure 4 shows the ThingSpeak API data upload algorithm.

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Figure 4: ThingSpeak API data upload algorithm

4. To load the pre-trained FCNN [9] model in Matlab Analysis module and to input the 22 data into the model for analysis to obtain the results. The model was trained using a publicly available dataset for Parkinson's Disease [10]. The Figure 5 shows the schematics of 3-Layer FCNN. Table 2 shows hyperparameters of 3-layer FCNN.





Name	Hyperparameters	
First Layer Size	10	
Second Layer Size	10	
Third Layer Size	10	
Activation Function	ReLU	
Iteration Limit	1000	
Learning Rate	0.01	
Learning Rate Update Algorithm	SGD	
Regularization Strength (Lambda)	0	
Standardize Data	Yes	

In Thingspeak, store the result value to file1 in the voice channel, and then the phone reads the value of file1 in the voice channel.

V. Results and Discussion

The process begins with receiving the initial signal from the microphone, then the signal goes through a number of preprocessing stages, including high-frequency isolation, noise suppression and segmentation of the speech frame using a Hamming window. Key characteristics are then extracted from these processed data and compiled into datasets. These data sets are transmitted to a neural network for training and optimization of the model, visually represented in the figure as a multi-layered structure. The completion of training and optimization is the creation of a model file capable of classifying voice input data. The experiment was conducted on an international dataset [11]. The results of test experiments in the IV network for the diagnosis of PD in patients with speech changes are shown in Table 3.

Table 3: The data of test experiments for speech recognition

Набор данных/	Средняя	Средняя	Средняя	Точность
Показатели	точность	чувствительность	F1 оценка	тестирования
БП по речи_	92,95%	92,95%	92,95%	94,7%

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The IoT network achieved 94.7% accuracy in diagnosing Parkinson's disease based on speech data and an F1 score of 92.95%. On the same data set, one of the best indicators of foreign studies is 95.8% [12], which indicates both good recognition results and the possibility of implementing an IV network for domestic PD diagnostics.

VI. Conclusions

In summary, the IoT network efficiently collects voice data from PD patients, processes it to remove noise, extracts essential features, and utilizes a 3-layer FCNN model to provide probability-based diagnostic outcomes, offering a viable solution for the timely detection of Parkinson's disease. Our work underscores the pivotal role of the IoT advancing healthcare. By seamlessly connecting devices and systems, IoT not only enables remote diagnostics but also promotes patient empowerment, personalized medicine, and enhanced healthcare delivery.

An approach using machine learning, neural networks, signal processing, and the Internet of Things (IoT) technologies for early detection of Parkinson's disease is described. A model and algorithms for processing audio signals from patients studied for the likelihood of Parkinson's disease are presented. The Internet of Things network collects voice data from PD patients, processes it to eliminate noise, extracts important characteristics, and uses a three-level FCNN model to obtain probability-based diagnostic results, offering a solution for timely detection of Parkinson's disease. 2. This work highlights the role of the Internet of Things in the development of IT diagnostics of patients. Thanks to the wireless connection of devices, the IoT network not only provides remote diagnostics, but also helps to empower patients and doctors, staff and improve the quality of medical care. As a result of experiments on an international dataset in the IV network, 94.7% accuracy was achieved in diagnosing Parkinson's disease based on speech data.

References Références Referencias

- Whitehouse PJ. Ethical issues in early diagnosis and prevention of Alzheimer disease. *Dialogues in Clinical Neuroscience*. 2019, Mar 31;21(1):101-108. DOI:10.31887/DCNS.2019.21.1/pwhitehouse.
- Giannakopoulou KM, Roussaki I, Demestichas K. Internet of things technologies and machine learning methods for Parkinson's disease diagnosis, monitoring and management: a systematic review. *Sensors.* 2022;22(5):1799. DOI:10.3390/s22051799.
- Vishniakou UA, YiWei X. IT Diagnostics of Parkinson's Disease Based on the Analysis of Voice Markers and Machine Learning. *Doklady BGUIR*. 2023;21(3):102-110. DOI:10.35596/1729-7648-2023 -21-3-102-110.
- 4. Upadhyay N, Karmakar A. Speech enhancement using spectral subtraction-type algorithms: A comparison and simulation study. *Procedia Computer Science*. 2015;54:574-84. DOI:10.1016/ j.procs.2015.06.066.
- 5. Dendrinos M, Bakamidis S, Carayannis G. Speech enhancement from noise: A regenerative approach. *Speech Communication*. 1991;10(1):45-57. http:// hdl.handle.net/123456789/10563
- Al-Barhan HA, Elyass SM, Saeed TR, Hatem GM, Ziboon HT. Modified speech separation deep learning network based on Hamming window. In: IOP Conference Series: *Materials Science and Engineering*. 2021;1076(1).
- Little M, Mcsharry P, Roberts S, Costello D, Moroz I. Exploiting nonlinear recurrence and fractal scaling properties for voice disorder detection. *Nature Precedings*. 2007;1-11. DOI:10.1186/1475-925X-6-23.
- 8. Pasha S. ThingSpeak based sensing and monitoring system for IoT with Matlab Analysis.

International Journal of New Technology and Research (IJNTR). 2016;2(6):19–23. Https://ieeex plore.ieee.org/abstract/document/7178838/

- Sainath TN, Vinyals O, Senior A, Sak H. Convolutional, long short-term memory, fully connected deep neural networks. In: 2015 *IEEE international conference on acoustics, speech and signal processing (ICASSP)*. IEEE. 2015:1-5. DOI:10. 1109/ICASSP.2015.7178838.
- Little M, McSharry P, Hunter E, Spielman J, Ramig L. Suitability of dysphonia measurements for telemonitoring of Parkinson's disease. Nature Precedings. 2008:1-27. DOI:10.1109/TBME.2008.20 05954.
- 11. Parkinson Data Set [Electronic resource]. Access mode: https://archive.ics.uci.edu/ml/datasets/parkin sons. Access date: 12.6.2024.
- Sakar BE, Isenkul ME, Sakar CO, Sertbas A. Collection and analysis of a Parkinson speech dataset with multiple types of sound recordings. *IEEE Journal of Biomedical and Health Informatics*, 2013, vol. 17(4), pp. 828–834. DOI:10.1109/JBHI. 2013.2245674.

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GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Validating Subsurface Samples of Volatile Black Oil through PVT Calculations of Surface Separator Samples for Enhanced Reservoir Characterization

By Godsday Idanegbe Usiabulu, Peter Sydney Aprioku, Ifeanyi Eddy Okoh & Glory Ochuwa Ayo University of Port Harcourt

Abstract- This study investigates black oil's pressure, volume, and temperature (PVT) properties from well X, analyzed using subsurface and surface recombination samples. Black oil samples were collected from the Q oil field and subjected to PVT analysis at the Reservoir Fluid Laboratory in Port Harcourt. Key findings include bubble point pressure (Pb) of 2000 psi, with a standing correlation value of 1934.3 psi, resulting in a 3.3% difference. The solution gas/oil ratio was measured at 647.3 SCF/STB, compared to 671.0 SCF/STB from correlations, a difference of 3.5%. The oil formation volume factor (Bo) was 1.456 res Bbl/STB, while standing correlations indicated 1.0675 res Bbl/STB, showing a 3.6% difference. The isothermal compressibility ranged from 10.12 x 10⁻⁶ psi⁻¹ at 4500 psi to 4.1309 x 10¹⁸ cp at 15 psi. Gas evolution began at 2000 psig and increased with decreasing pressure. Viscosity varied significantly, recorded at 0.54 cp at 4500 psig and 1.38 cp at 15 psig.

Keywords: black oil, formation volume factor reservoir heavy crude absolute error. GJRE-J Classification: LCC: TN871.2

VALIDATINGSUBSURFACESAMPLESOFVOLATILE BLACKOILTHROUGHPVTCALCULATIONSOFSURFACESEPARATORSAMPLESFORENHANCEDRESERVOIRCHARACTERIZATION

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Validating Subsurface Samples of Volatile Black Oil through PVT Calculations of Surface Separator Samples for Enhanced Reservoir Characterization

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Abstract- This study investigates black oil's pressure, volume, and temperature (PVT) properties from well X, analyzed using subsurface and surface recombination samples. Black oil samples were collected from the Q oil field and subjected to PVT analysis at the Reservoir Fluid Laboratory in Port Harcourt. Key findings include bubble point pressure (Pb) of 2000 psi, with a standing correlation value of 1934.3 psi, resulting in a 3.3% difference. The solution gas/oil ratio was measured at 647.3 SCF/STB, compared to 671.0 SCF/STB from correlations, a difference of 3.5%. The oil formation volume factor (Bo) was 1.456 res Bbl/STB, while standing correlations indicated 1.0675 res Bbl/STB, showing a 3.6% difference. The isothermal compressibility ranged from 10.12 x 10⁻⁶ psi⁻¹ at 4500 psi to 4.1309 x 10¹⁸ cp at 15 psi. Gas evolution began at 2000 psig and increased with decreasing pressure. Viscosity varied significantly, recorded at 0.54 cp at 4500 psig and 1.38 cp at 15 psig. The reservoir contains heavy crude oil with an API rating of 30 and an average absolute error of 3.5% (0.035). These results enhance reservoir characterization and validate the use of PVT calculations in analyzing volatile black oil samples.

Keywords: black oil, formation volume factor reservoir heavy crude absolute error.

I. INTRODUCTION

A reservoir is a subsurface rock formation containing liquids and gaseous hydrocarbons, typically found in sedimentary basins. When a well is drilled, reservoirs can release hydrocarbon fluids at specific rates. Understanding the properties of these fluids is crucial for effective reservoir management and economic forecasting in petroleum engineering.

Black oils, as defined by Ahmed (2016), are hydrocarbon fluids that exist as liquids with an average gas-to-oil ratio (GOR) of 3000 ft³/BBL. The analysis of pressure, volume, and temperature (PVT) properties of reservoir fluids is essential for assessing the economic

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worth of a reservoir. The three main types of reservoir fluids based on phase diagrams are oil, gas, and condensate.

PVT properties of black oil are best measured in a laboratory setting using a PVT cell with bottom-hole or recombined samples under reservoir conditions (Tower, 2002). The measured properties of crude oil and its dissolved gases can vary significantly depending on the measurement conditions. Therefore, a series of standard tests are conducted to determine these properties. For black oil, viscosity tests are particularly critical, as a precise description of physical properties is vital for reservoir engineering studies (El-Hoshoudy, 2019). Key properties include fluid gravity, specific gravity, solution gas/oil ratio, bubble point pressure (Pb). formation volume factor (Bo). isothermal oil compressibility (Co), oil density (po), and crude oil viscosity (µo) (Zamani, 2015).

In the absence of experimentally measured data, petroleum engineers must rely on empirically derived correlations to estimate these properties (Standing, 1947). This research aims to validate PVT parameters in saturated black oil reservoirs using standing correlations, as outlined by Nojabaei and Johns (2016). The study seeks to enhance the understanding of black oils and improve reservoir management strategies, ultimately contributing to more accurate economic assessments in the oil industry by confirming these parameters

II. METHODOLOGY

a) Viscosity

This section outlines the procedure for measuring the viscosity of black oil at reservoir pressure and temperature using a high-pressure rolling-ball viscosimeter. Accurate viscosity measurements are crucial for understanding fluid behaviour in reservoir engineering, as they directly impact hydrocarbon recovery processes.

b) Equipment

The high-pressure rolling-ball viscosimeter is designed to measure the viscosity of fluids under controlled pressure and temperature conditions. It operates by timing how long a precision steel ball rolls a

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specific distance through the oil. This method is chosen for its reliability in simulating reservoir conditions.

- c) Procedure
- 1. Vacuum the Viscometer: Begin by vacuuming the viscometer for at least one hour to remove any air trapped in the system. This step is critical to prevent gas bubbles from affecting the viscosity measurements (Gaganis & Varotsis, 2016).
- 2. Set Temperature: Adjust the viscosimeter to the reservoir temperature. Ensuring the correct temperature is vital, as viscosity is temperature-dependent.
- 3. *Fill the Viscosimeter:* Introduce the oil sample into the viscosimeter at a pressure above the reservoir pressure. This ensures that the sample remains liquid and prevents gas evolution.
- 4. Achieve Thermal Equilibrium: Gently rock the housing with the barrel seal open. This action helps stir the liquid and ensures thermal equilibrium throughout the sample, allowing for accurate pressure adjustments (Elkatatny & Mahmoud, 2018).
- 5. *Position the Ball:* Invert the housing so the ball rests against the barrel seal. This setup ensures that the ball is ready to drop through the fluid.
- 6. *Release the Ball:* Turn the housing to a 70° angle and shut the barrel seal. Release the ball and record the time it takes to fall through the fluid. Repeat this procedure for angles of 45° and 23° (Standing, 1947).
- 7. Lower Pressure: Reduce the pressure to the next lower level and retake fall time readings. This step

allows for viscosity measurements at various pressures.

- 8. Rocking at Bubble Point: When working at or below the bubble-point pressure, shut the outlet valve while rocking the barrel to maintain the sample's integrity. Repeat steps 5-6 for each pressure point down to atmospheric pressure (EI-Hoshoudy, 2018).
- 9. *Calculate Viscosity:* Convert the recorded fall times to viscosity values using calibration curves specific to the instrument. These curves are derived from standard fluids with known viscosities to ensure measurement accuracy (EI-Hoshoudy&Desouky, 2018).
- d) Calibration Process

The calibration curve is established by measuring the fall times of a standard fluid with known viscosity at various pressures and temperatures. This curve is then used to convert the measured fall times of the black oil sample into viscosity values, ensuring consistency and accuracy in the results.

e) Error Mitigation

Temperature fluctuations and improper calibration are potential sources of error in viscosity measurements. To mitigate these issues, ensure that the viscosimeter is properly calibrated before use and that temperature is consistently monitored throughout the testing process.

This methodology provides a reliable framework for measuring the viscosity of black oil under reservoir conditions. Future research could explore advancements in viscosity measurement techniques or alternative methodologies that may enhance accuracy and efficiency.

III. Results and Discussion

a) Validation of Oil Viscosity (μ_0) at Flash Conditions

For $P > P_b$

$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

$$M = 2.6P^{1.187} e^{[-11.513 - 8.98(10^{-5})P]}$$

For P = 4500 psi

 $M = 2.6(4500)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 4500]}$ $M = 2.6(4500)^{1.187} e^{-11.9171}$ M = 0.3765

From $\log_{10}[\log_{10}(\mu_{obd} + 1) = 1.8653 - 0.025086(\gamma_o.API) - 0.5644\log TR$

$$\log_{10}[\log_{10}(\mu_{od} + 1) = 1.8653 - 0.025086(30) - 0.5644\log(186)]$$

$$= -0.16819$$
$$\log_{10}(\mu_{od} + 1) = \log_{10}^{-1} - 0.16819$$
$$\log_{10}(\mu_{od} + 1) = 0.67890$$
$$\mu_{od} + 1 = \log_{10}^{-10.67890}$$
$$\mu_{od} + 1 = 4.7743$$
$$\mu_{od} = 4.7743 - 1$$
$$\mu_{od} = 3.7743 CP$$

From $\mu_{ob} = A \mu_{ob}^{B}$

 $A = 10.715 (R_{so} + 100)^{-0.515}$ $B = 5.44 (R_{so} + 150)^{-0.338}$

At $P = 4500 \, psi$, $R_{so} = 1781.5 \, SCF \, / \, STB$

$$A = 0.22061$$

 $B = 0.42166$
 $\mu_{ob} = A \mu_{ob}^{\ \ B}$

 $A = 0.2206, B = 0.42166, \mu_{obd} = 3.7742 CP$

$$\mu_{ob} = 0.2206(3.77420)^{0.42166}$$
$$\mu_{ob} = 0.3862 CP$$
$$\mu_{ob} = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

 $\mu_{ob} = 0.3862, P = 4500 \text{ psi}, P_b = 2000 \text{ psi}, M = 0.3765$

$$\mu_{ob} = 0.3862 \bigg(\frac{4500}{2000} \bigg)^{0.3765}$$

For P = 4000 psi

$$\mu_{ab} = 0.524 CP$$
For P = 4000 psi

$$M = 2.6 P^{1.187} e^{[-11.513-8.98(10^{-3})\times 4000]}$$

$$M = 2.6(4000)^{1.187} e^{[-11.513-8.98(10^{-3})\times 4000]}$$

$$M = 2.6(4000)^{1.187} e^{-11.8722}$$

$$M = 0.3424$$

$$\log_{10}[\log_{10}(\mu_{od} + 1) = 1.8653 - 0.025086(30) - 0.5644 \log(186)$$

$$= -0.16819$$

$$\log_{10}(\mu_{od} + 1) = \log_{10}^{-1} - 0.16819$$

$$\log_{10}(\mu_{od} + 1) = 0.67890$$

$$\mu_{od} + 1 = \log_{10}^{-10.67890}$$

$$\mu_{od} + 1 = 4.7743$$

$$\mu_{od} = 3.7742 CP$$
From $\mu_{ab} = A \mu_{ob}^{-B}$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$

$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For $P = 4000 \, psi, R_{so} = 1545.9 \, SCF \, / \, STB$

$$A = 10.715(1545.9 + 100)^{-0.515}$$

$$A = 0.4406$$

$$B = 5.44(1545.9 + 150)^{-0.338}$$

$$B = 0.4406$$

$$\mu_{ob} = A \ \mu_{ob}^{B}$$

$$\mu_{od} = 0.2363(3.7742)^{0.4406}$$

$$\mu_{od} = 0.4242 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.4723 \left(\frac{4000}{2000}\right)^{0.3424}$$

$$\mu_{ob} = 0.5378 CP$$

$$M = 2.6 P^{1.187} e^{[-11.513 - 8.98(10^{-5})P]}$$

$$M = 2.6(3500)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 3500]}$$

$$M = 2.6(3500)^{1.185} e^{-11.8273}$$

$$M = 0.3057$$

$$\mu_{ob} = 3.7742 CP$$

From $\mu_{ob} = A \mu_{ob}^{B}$

For $P = 3500 \, psi$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For $P = 3500 \ psi, R_{so} = 1316.3 \ SCF \ / \ STB$

$$A = 10.715 (1316.3 + 100)^{-0.515}$$

$$A = 0.2554$$

$$B = 5.44 (1316.3 + 150)^{-0.338}$$

$$B = 0.4628$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

 $A=0.2554,\,B\!=\!0.4628,\,\mu_{ob}\!=\!3.7742CP$

$$\mu_{od} = 0.2554 (3.7742)^{0.4628}$$
$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

$$\mu_{ob} = 0.4723 \left(\frac{3500}{2000}\right)^{0.3057}$$

 $\mu_{ob} = 0.5604 \, CP$

For $P = 3000 \, psi$

$$M = 2.6 (3000)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 3000]}$$
$$M = 0.2662$$
$$\mu_{obd} = 3.7742 CP$$
$$\mu_{ob} = A \ \mu_{ob}^{B}$$
$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For P = 3000 psi, $R_{so} = 1093.4 \text{ SCF} / \text{STB}$

 $A = 10.715 (1093.4 + 100)^{-0.515}$ A = 0.2789 $B = 5.44 (1093.4 + 150)^{-0.338}$ B = 0.4894 $\mu_{od} = 0.2789 (3.7742)^{0.4894}$ $\mu_{od} = 0.5342 CP$ $\mu_{o} = \mu_{ob} \left(\frac{P}{P_b}\right)^M$ $\mu_{ob} = 0.5342 \left(\frac{3000}{2000}\right)^{0.2662}$ $\mu_{ob} = 0.5951 CP$ P = 2575 psi $M = 2.6 (2575)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 2575]}$ $M = 2.6 (2575)^{1.187} e^{-11.744235}$

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M = 0.23073 $\mu_{obd} = 3.7742 CP$ $\mu_{ob} = A \mu_{ob}^{B}$ $A = 10.715 (R_{so} + {}^{-0.515})$ $B = 5.44 (R_{so} + 150)^{-0.338}$

For $P = 2575 \, psi, R_{so} = 909.7 \, SCF / STB$

 $A = 10.715(909.7 + 100)^{-0.515}$ A = 0.30397 $B = 5.44(909.7 + 150)^{-0.338}$ B = 0.51652 $\mu_{ob} = A \mu_{ob}^{B}$ $\mu_{od} = 0.30397 \ (3.7742)^{0.51652}$ $\mu_{od}=0.60363$ $\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$ $\mu_{ob} = 0.60363 \left(\frac{2575}{2000}\right)^{0.23073}$ $\mu_{ob} = 0.6399 CP$ At P=2420 psi $M = 2.6(2420^{1.18})_{0^{[-11.513-8.98(10^{-5})\times 2575]}}$ $M = 2.6(2420^{1.18})_{a^{-11.730316}}$ M = 0.21735 $\mu_{ob} = 3.7742 CP$ $A = 10.715 (R_{so} + 100)^{-0.515}$

 $B = 5.44 (R_{so} + 150)^{-0.338}$

For $P = 2420 \, psi, R_{so} = 844.2 \, SCF \, / \, STB$

 $A = 10.715(844.2 + 100)^{-0.515}$ A = 0.31465 $B = 5.44 (844.2 + 150)^{-0.338}$ B = 0.52778 $\mu_{ob} = A \mu_{ob}^{B}$ $\mu_{od} = 0.31465 (3.7742)^{0.4894}$ $\mu_{od} = 0634256 \ CP$ $\mu_o = \mu_{ob} \left(\frac{P}{P_h}\right)^M$ $\mu_{ob} = 0.634256 \left(\frac{2420}{2000}\right)^{0.21735}$ $\mu_{ob}=0.66109CP$ $P = 2000 \, psi$ $M = 2.6(2000^{1.18})_{0^{[-11.513-8.98(10^{-5})\times 2575]}}$ $M = 2.6(2000^{1.18})_{e^{-11.730316}}$ M = 0.180 $\mu_{obd} = 3.7743 CP$ $\mu_{ob} = A \mu_{ob}^{B}$ $A = 10.715 \left(R_{so} + 100 \right)^{-0.515}$ $B = 5.44 (R_{so} + 150)^{-0.338}$

At $P = 2000 \, psi, R_{so} = 671.03SCF / STB$

 $A = 10.715(671.03 + 100)^{-0.515}$

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	A= 0.34926
	$B = 5.44 \ (671.03 + 150)^{-0.338}$
	B = 0.56305
	$\mu_{ob} = A \ \mu_{ob}^{B}$
	$\mu_{od} = 0.3492(3.7743)^{0.56305}$
	$\mu_{od} = 73767 \ CP$
	$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$
	$\mu_{ob} = 0.73767 \left(\frac{2000}{2000}\right)^{0.180}$
	$\mu_{ob} = 0.73767 CP$
	$P = 1600 \ psi$
	$M = 2.6 P^{1.187_{e^{[-11.513-8.98(10^{-5})P]}}}$
	$M = 2.6(1600)^{1.187_{e^{[-11.513-8.98(10^{-5})\times 1600]}}}$
	$M = 2.6 (1600)^{1.187_{e^{-11.65668}}}$
	<i>M</i> = 0.143163
	$\mu_{obd} = 3.7743 CP$
	$\mu_{ob} = A \ \mu_{ob}^{B}$
	$A = 10.715 \left(R_{so} + 100 \right)^{-0.515}$
	$B = 5.44 (R_{so} + 150)^{-0.338}$
$R_{so} = 512.9SCF / STB$	

At P = 1600 psi, K

For $P < P_h$

$$A = 10.715(512.9 + 100)^{-0.515}$$
$$A = 0.39309$$

$$B = 5.44 (512.9 + 150)^{-0.338}$$

$$B = 0.60527$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$\mu_{od} = 0.39309 (3.7743)^{0.60527}$$

$$\mu_{od} = 5342 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.87828 \left(\frac{1600}{2000}\right)^{0.143163}$$

$$\mu_{ob} = 0.8507 CP$$

$$M = 2.6 (1200)^{1.187} e^{-11.513 - 8.98(10^{-5}) \times 12001}$$

$$M = 2.6 (1200)^{1.187} e^{-11.63976}$$

$$M = 0.10547$$

$$\mu_{obd} = 3.7743 CP$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$

$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For P=1200 psi

For $P = 1200 \, psi, R_{so} = 362.78SCF / STB$

$$A = 10.715 (362.78 + 100)^{-0.515}$$
$$A = 0.45428$$
$$B = 5.44 (362.78 + 150)^{-0.338}$$
$$B = 0.66015$$
$$\mu_{ob} = A \ \mu_{ob}^{\ B}$$

$$\mu_{od} = 0.45428 (3.7743)^{0.66015}$$

$$\mu_{od} = 1.092 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

$$\mu_{ob} = 0.5342 \left(\frac{1200}{2000}\right)^{0.10547}$$

$$\mu_{ob} = 1.0347 CP$$

$$M = 2.6 (800)^{1.187} e^{(-11.513-8.98(10^{-5}) \times 800)}$$

$$M = 2.6 (800)^{1.187} e^{-11.62076}$$

$$M = 0.06756$$

$$\mu_{obd} = 3.7743 CP$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$

$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For P = 800 psi

- $For P = 800 \, psi, R_{so} = 222.65 SCF \, / \, STB$
 - $A = 10.715 (222.65 + 100)^{-0.515}$ A = 0.5470 $B = 5.44 (222.65 + 150)^{-0.338}$ B = 0.73539 $\mu_{ob} = A \ \mu_{ob}^{B}$ $\mu_{od} = 0.5470 (3.7743)^{0.73539}$ $\mu_{od} = 1.45274 \ CP$ $\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$

$$\mu_{ob} = 0.5342 \left(\frac{800}{2000}\right)^{0.10547}$$
$$\mu_{ob} = 1.36554 \, CP$$

For P = 400 psi

$$M = 2.6 (400)^{1.187} e^{[-11.513-8.98(10^{-5}) \times 400]}$$
$$M = 2.6 (400)^{1.187} e^{-11.54892}$$
$$M = 0.03076$$
$$\mu_{obd} = 3.7743 CP$$
$$\mu_{ob} = A \mu_{ob}^{B}$$
$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

 $At P = 400 \ psi, R_{so} = 96.64 SCF / STB$

$$A = 0.93053 A = 10.715 (96.64 + 100)^{-0.515}$$

$$A = 0.7059$$

$$B = 5.44 (96.64 + 150)^{-0.338}$$

$$B = 0.84544$$

$$\mu_{ob} = A \ \mu_{ob}^{B}$$

$$\mu_{od} = 0.5470 (3.7743)^{0.84544}$$

$$\mu_{od} = 2.1698 \ CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.5342 \left(\frac{400}{2000}\right)^{0.03076}$$

$$\mu_{ob} = 2.06499 \ CP$$

$$\mu_{o} = 2.0645 \ CP$$

For P=15 psi

$$M = 2.6 (15)^{1.187} e^{[-11.513-8.98(10^{-5})\times 15]}$$
$$M = 2.6 (800)^{1.187} e^{-11.501247}$$
$$M = 0.6.5467 \times 10^{-4}$$
$$\mu_{obd} = 3.7743 CP$$
$$\mu_{ob} = A \ \mu_{ob}^{\ B}$$
$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

 $At P = 15 psi, R_{so} = 1.85SCF / STB$

$$A = 10.715 (15 + 100)^{-0.515}$$

$$B = 5.44 (15 + 150)^{-0.338}$$

$$B = 0.968477$$

$$\mu_{ob} = A \ \mu_{ob}^{B}$$

$$\mu_{od} = 0.93053 (3.7743)^{0.968477}$$

$$\mu_{od} = 3.36809 \ CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 3.36809 \left(\frac{15}{2000}\right)^{6.5467 \times 10^{-4}}$$

$$\mu_{ob} = 4.1309 \times 10^{-4} \ CP$$

$$\mu_{o} = 4.1309 \times 10^{-4} \ CP$$

Where $\mu_{ob} = dead \ oil \ vis \cos ity, \ CP$

 $\mu_{ob} = oil vis \cos ity at bubble point pressure in CP$ $\mu_o = oil \ vis \cos ity \ in \ CP$

b) Tables of Value for Complete PVT Report

Table 1: Validation of PVT Parameters using Standing Correlations (Dessouky and El-hoshoudy, 2018)

P PSIG	R _{so} SCF/STB	B _o BBL/STB	C _o (PSt ¹)	μ _ο CP
4500	1781.5	1.041	10.12 × 10 ⁻⁶	0.524
4000	1545.9	1.041	11.39 × 10 ⁻⁶	0.5378
3500	1316.3	1.047	13.02 × 10 ⁻⁶	0.5604
3000	1093.4	1.0514	15.19 × 10⁻ ⁶	0.5951
2575	909.7	1.057	17.7 × 10⁻ ⁶	0.6399
2420	844.2	1.0591	18.83× 10 ⁻⁶	0.66109
2000	671.03	1.0675	17.31 × 10⁻ ⁶	0.73767
1600	512.9	1.0661	26.02 × 10⁻⁵	0.8507
1200	362.78	1.0645	43.98 × 10⁻⁵	1.0347
800	222.65	1.0630	92.18 × 10⁻⁵	1.36554
400	96.64	1.0617	32.66 × 10⁻⁵	2.065
15	1.85	1.0607	13.08 × 10⁻⁵	4.1309 × 10 ¹⁸

c) Validation of PVT Parameters using Standing Correlations

i. Estimation of Bubble Point Pressure (P_b)

From standing correlations for the reservoir condition (Rafiee-Taghanaki, 2013)

 $R_{Sb}=$ 647.3 SCF/STB, TR - 186°F, $\gamma_g=$ 1.306, $\gamma_o API=$ 30°API

$$\mathsf{P}_{\mathsf{b}} = 18 \left(\frac{R_{Sb}}{\gamma_g} \right)^{0.83} 10^{\gamma_g}$$

$$y_{g} = 0.00091 \text{ TR} - 0.0125 \gamma_{o} \text{API}$$

$$y_{g} = 0.00091 (186) - 0.0125 (30)$$

$$y_{g} = -0.20574$$

$$P_{b} = 18 \left(\frac{647.3}{1.306}\right)^{0.83} 10^{-0.20574}$$

$$P_{b} = 18(495.6)^{0.83} \times 0.7383$$

$$P_{b} = 1934.271 \text{ psi}$$

The bubble pressure = 1934.271psi

(Dessouky and El-hoshoudy, 2018).

ii. Validation of Solution Gas/Oil Ratio at Flash Condition Solution Gas/Oil Ratio (R_{so})

1

 $P < P_{\rm b}$

$$R_{SO} = \gamma_g \left[\frac{P}{18(10)^{-Yg}}\right]^{1.204}$$

$$\gamma_{g} = 1.306, P = 2000PSI, TR = 186^{\circ}F, \gamma_{o}API = 30$$

ATTILE BLACK OIL THROUGH PVT CALCULATION
EMMANCED RESERVOIR CHARACTERIZATION

$$\gamma_{g} = 0.00091 (180) - 0.0125 (30)$$

 $\gamma_{g} = 0.20574$
 $\therefore R_{SO} = 1.306 \left[\frac{2000}{18(10)^{-0.20574}} \right]^{1.204}$
 $= 6710.03 \text{ SCF/STB}$
 $P = 1600 \text{ PSI}$
 $R_{SO} = 1.306 \left[\frac{1600}{18(10)^{-0.20574}} \right]^{1.204}$
 $= 512.9 \text{ SCF/STB}$
 $P = 1200 \text{ PSI}$
 $R_{SO} = 1.306 \left[\frac{1200}{18(10)^{-0.20574}} \right]^{1.204}$
 $= 362.78 \text{ SCF/STB}$
 $P = 800 \text{ PSI}$
 $R_{SO} = 1.306 \left[\frac{800}{18(10)^{-0.20574}} \right]^{1.204}$
 $= 22.65 \text{ SCF/STB}$
 $P = 400 \text{ PSI}$
 $R_{SO} = 1.306 \left[\frac{400}{18(10)^{-0.20574}} \right]^{1.204}$
 $= 96.64 \text{ SCF/STB}$
 $P = 15 \text{ PSI}$
 $R_{SO} = 1.306 \left[\frac{15}{18(10)^{-0.20574}} \right]^{1.204}$

(Zamani, H. et al., 2015).

 $\mathsf{P} > \mathsf{P}_{\mathsf{b}}$

P = 4500 PSI

VALIDATING SUBSURFACE SAMPLES OF VOLATILE BLACK OIL THROUGH PVT CALCULATIONS OF SURFACE SEPARATOR SAMPLES FOR ENHANCED RESERVOIR CHARACTERIZATION

> $R_{so} = 1.306 \left[\frac{4500}{18(10)^{-0.20574}} \right]^{1.204}$ = 1781.5 SCF/STB Ρ = 4000 PSI $R_{so} = 1.306 \left[\frac{4000}{18(10)^{-0.20574}} \right]^{1.204}$ = 1,545.9 SCF/STB P = 3500 PSI $R_{SO} = 1.306 \left[\frac{3500}{18(10)^{-0.20574}} \right]^{1.204}$ = 1,316.3 SCF/STB P = 3000 PSI $R_{SO} = 1.306 \left[\frac{3000}{18(10)^{-0.20574}} \right]^{1.204}$ = 1,093.4 SCF/STB Ρ = 2575 PSI $R_{so} = 1.306 \left[\frac{2575}{18(10)^{-0.20574}} \right]^{1.204}$ = 909.7 SCF/STB Ρ = 2420 PSI $R_{so} = 1.306 \left[\frac{3000}{18(10)^{-0.20574}} \right]^{1.204}$ = 844.2 SCF/STB

iii. Validation of Oil Isothermal Compressibility (C_o) at Flash Condition

 $\mathsf{P} < \mathsf{P}_{\mathsf{b}}$

$$C_o = \frac{(5R_{sb} + 17.2T - 1180\gamma_g + 12.61\gamma_o.API - 1433)}{p(10)^5}$$

 $RS_{ob}=$ 647.3 SCF/STB, TR= 186°F, $\gamma_g=$ 0.698, $\gamma_o.API=$ 30

FOR P = 4500 psi

+ 0.262 ln (γ_o.API)

 $P = 2000 \text{ psi}, TR = 186^{\circ}F, \gamma_{o}.API = 30$

 $InC_{o} = -0.664 - 1.430 In 2000 - 0.395 In 2000 + 0.390 In 186 + 0.455)647.3)$

 $FOR = P \le P_b$

+ 0.262 ln (30)

 $InC_{0} = -8.66136$ $InC_{O} = e^{-8.66136}$ = 17.31 × 10⁻⁵ psi⁻¹ P = 1600 psi $InC_{o} = -0.664 - 1.430 In 1600 - 0.395 In 1600 + 0.390 In 186 + 0.455 (647.3)$ + 0.262 ln (30) $InC_{o} = -8.25412$ InC₀ e^{-8.25412} $InC_{O} = 26.02 \times 10^{-5} \text{ psi}^{-1}$ P = 1200 psi $InC_{0} = -0.664 - 1.430 In 1200 - 0.395 In 1200 + 0.390 In 186 + 0.455 (647.3)$ + 0.262 ln (30) $InC_{o} = -7.7291$ $InC_{O} = e^{7.7291}$ $InC_{O} = 43-98 \times 10^{-5} \text{ Psi}^{-1}$ P = 800 psi $InC_{o} = -0.664 - 1.430 In 800 - 0.395 In 800 + 0.390 In 186 + 0.455 (647.3)$ + 0.262 ln (30) $InC_{o} = -60.9813$ $InC_{O} = e^{-6.9813}$ $InC_{o} = 92.18 \times 10^{-5} \text{ Psi}^{-1}$ P = 400 psi $InC_{o} = -0.664 - 1.430 In 400 - 0.395 In 400 + 0.390 In 186 + 0.455 (647.3)$ + 0.262 ln (30) $lnC_{0} = -5.72414$ $InC_{O} = e^{-5.72414}$ $InC_{O} = 32.66 \times 10^{-4} \text{ Psi}^{-1}$ P = 15 psi $InC_{o} = -0.664 - 1.430 In 15 - 0.395 In 15 + 0.390 In 186 + 0.455 (647.3)$

+ 0.262 ln (30)

 $InC_{o} = -0.26809$

$$\ln C_{\odot} = e^{-0.26809}$$

 $InC_{o} = 13.08 \times 10^{-4} \text{ Psi}^{-1}$

iv. Validation of Oil Formation Volume Factor (B_o) at Flash Conditions

FROM
$$B_O = B_{Obe^{[Co(Pb-P)]}}$$

Where

$$B_{ob} = 0.972 + 0.000147 F^{1.175}$$

$$\mathsf{F} = \mathsf{R}_{\mathsf{sob}} \left(\frac{\gamma_{\mathsf{g}}}{\gamma_o.API} \right) + 1.25 \,\mathsf{TR}$$

$$R_{ob} = 647.3 \frac{SCF}{STB}, \gamma_g = 0.698_{\gamma o}, API = 30TR = 186^{\circ} F$$

$$F = 647.3 \left(\frac{0.698}{30}\right) + 1.25 \ (186)$$
$$F = 247.5605$$

$$B_{ob} = 0.972 + 0.000147 (247.5605)^{1.175}$$

 $B_{ob} = 1.0675 \text{ Res. BBL/STB}$

 $\mathsf{P} > \mathsf{P}_{\mathsf{b}}$

P = 4500 psi

$$\begin{split} \mathsf{B}_{ob} &= 1.0675 \; \frac{BBL}{STB}, \ \mathsf{C} \ \mathsf{O} &= 10.12 \times 10^{-1} \ \mathsf{Psi^{-1} \ Pb} = 2000 \ \mathsf{psi} \\ \mathsf{B}_{ob} &= .0675_{e^{10.12 \times 10^{-6}}} \ (2000 - 4500) \\ B_{ob} \; 1.0675_{e^{-0.0253}} \\ \mathsf{B}_{ob} &= 1.041 \ \mathsf{BBL}/\mathsf{STB} \\ \mathsf{P} &= 4000 \ \mathsf{psi} \\ \mathsf{B}_{ob} &= 1.0675 \ \mathsf{BBL}/\mathsf{STB}, \ \mathsf{CO} &= 10.12 \times 10^{-1} \ \mathsf{Psi^{-1} \ Pb} = 2000 \ \mathsf{psi} \end{split}$$

$$B_{ob} = 1.0675_{e^{(11.39\times10^{-6})}} (2000 - 4000)$$
$$B_{ob} = 1.0675_{e^{-0.02278}}$$
$$B_{ob} = 1.041 \text{ BBL/STB}$$
$$B_{ob} = 1.0675_{e^{(15.19\times10^{-6})}} (2000 - 3000)$$
$$B_{ob} = 1.0675_{e^{-0.0159}}$$

$$B_{ob} = 1.0514 \text{ BBL/STB}$$

$$P = 2575 \text{ psi}$$

$$B_{ob} = 1.0675_{e^{1077\times10^{-6}}} (2000 - 2575)$$

$$B_{ob} = 1.0675_{e^{-0.0101775}}$$

$$B_{ob} = 1.0675 \text{ BBL/STB}$$

$$P = 2000 \text{ psi}$$

$$B_{ob} = 1.0675_{e^{0}}$$

$$B_{ob} = 1.0675 \text{ BBL/STB}$$

$$B_{o} = 0.972 + 0.000147\text{F}^{1.175}$$

$$F = R_{so} = \left(\frac{\gamma_g}{\gamma_o.API}\right) + 1.25TR$$

$$P = 1600 \text{ Psi}$$

$$R_{so} = \gamma$$

$$F = 512.9 \left(\frac{0.698}{30}\right) + 1.25 (186)$$

$$F = 244.433$$

$$B_o = 0.972 + 0.000147 (244.433)^{1.175}$$

$$B_o = 1.0661 \text{ BBL/STB}$$

$$P = 1200 \text{ Psi}$$

$$R_{so} = 362.78 \text{ SCF/STB}$$

$$F = 362.78 \left(\frac{0.698}{30}\right) + 1.25 (186)$$

$$F = 240.9406$$

$$B_o = 0.972 + 0.000147 \text{ F}^{1.175}$$

$$B_o = 1.0645 \text{ BBL/STB}$$

$$P = 800 \text{ Psi}$$

 $\mathrm{R_{so}}=222.65~\mathrm{SCF/STB}$

 $\mathsf{F} = 222.65 \left(\frac{0.698}{30} \right) + 1.25(186)$ F = 237.6803 $B_0 = 0.972 + 0.000147 (237.6803)^{1.175}$ $B_o = 1.0630 BBL/STB$ P = 400 Psi $R_{so} = 96.64 \text{ SCF/STB}$ $\mathsf{F} = 96.64 \left(\frac{0.698}{30} \right) + 1.25(186)$ F = 234.748 $B_0 = 0.972 + 0.000147 (234.748)^{1.175}$ $B_0 = 1.0617 BBL/STB$ P = 15 Psi $R_{so} = 1.85 \text{ SCF/STB}$ $\mathsf{F} = 1.85 \bigg(\frac{0.698}{30} \bigg) + 1.25(186)$ F = 232.543 $B_0 = 0.972 + 0.000147 (232.543)^{1.175}$ $B_0 = 1.067 BBL/STB$

v. Validating of the PVT Parameters

1) The Bubble point pressure P_{b}

The bubble point pressure P_b has average error of 4.8% plotted for about 105 data point with the following ranges. (Rafiee-Taghanaki et al 2013).

2) The solution gas/oil ratio (R_{SO}) is valid For 20 SCF/STB $< R_{Sb} < 1,425$ SCF/STB

$$16.5^{\circ} \text{API} < \gamma_{\circ} \text{API} < 63.8^{\circ} \text{API}$$

$$0.59 < \gamma_g < 0.95$$

The solution $\frac{gas}{oil}$ ratio (R_{so}) is valid with average error of 2.3%.

- 3) The oil formation volume factor B_{0} is valid for the range of 1.024 < B < 2.05 RB/STB The oil formation volume factor (B_{0}) had average error of 26.9%
- 4) The oil compressibility value jumps discontinuously from $18.83 \times 10^{-6}_{psi^{-1}}$ above the bubble to $26.02 \times 10^{-6}_{psi^{-1}}$ just below bubble point pressure, because oil is usually much more compressible below the bubble point (Oyedeko and Ulaeto, 2011).

5) The oil viscosity μ_0 had an average absolute error for the standing correlation is 7.54% in the range

126 psig < P < 9,500 psig

 $0.117 \text{ cp} < \gamma_q < 1.351$

The oil viscosity jumps from 0.737cp at P_b to 4.1309 × 10¹⁸ cp at pressure of 15sig because the oil viscosity is sensitive to pressure charges.

IV. DISCUSSION OF RESULT

a) Overview of Findings

This study provides critical insights into the behaviour of black oil in a reservoir context, mainly focusing on bubble point pressure, formation volume factor, and viscosity. Understanding these properties is essential for effective reservoir management and hydrocarbon recovery.

b) Bubble Point Pressure

As oil wells are drilled and completed, a point is reached where the gas dissolved in crude oil begins to bubble out, forming a two-phase region. This pressure is called the bubble point (Pb) (EI-Hoshoudy & Desouky, 2018). The PVT analysis determined a bubble point pressure of 2000 psig, while the standing correlation provided a Pb of 1937.371 psi, resulting in a difference of 65.7 psi. This discrepancy likely arises from the representativeness of the PVT samples collected. Accurate representation is crucial, as variability in sampling can lead to significant errors in predicted reservoir behaviour (Okoduwa & Ikiensikimama, 2010).

c) PVT Analysis

To ensure reliable results, PVT samples must accurately reflect the reservoir fluid in situ. The expansion of reservoir fluids is a function of pressure, and calculations should be made using various total two-phase expansion factors. To achieve reliable results, these factors must be weighted by volume (El-Hoshoudy, 2019). Current commercial laboratory equipment for PVT analysis can determine volume with a maximum error of less than 0.01% and temperature within 1% (Shokrollahi et al., 2015).

d) Formation Volume Factor

The formation volume factor (Bo) relates the volume of oil at reservoir conditions to its volume at stock tank conditions. At standard conditions of 0 psig and 60°F, Bo should equal unity. Above the bubble point, Bo increases as oil compressibility (Co) decreases, while below the bubble point, Bo decreases as Co increases (Moradi, 2013). The findings indicate that above Pb, Co was measured at $18.83 \times 10 < sup > -6 </sup > psi < sup > -1 </sup >, and below Pb, at 1600 psi, Co increased to <math>26.02 \times 10 < sup > -5 </sup > psi < sup > -1 </sup >. At atmospheric pressure, Co decreased to <math>13.08 \times 10 < sup > -1 </sup > psi < sup > -1 </sup > 1 </sup > . This demonstrates that oil compressibility is significantly influenced by reservoir pressure.$

e) Viscosity

Oil's viscosity (μ o) is another critical property, as it directly affects the flow rate. Above the bubble point, μ o increases as pressure decreases. Below Pb, viscosity increases dramatically from 1.0347 cp at 1200 psig to 4.1309 \times 10¹⁸ cp at 15 psig, indicating that viscosity is highly sensitive to pressure changes. The viscosity and flow rate relationship is inversely proportional; higher viscosity results in lower flow rates (Ahmed, 2016).

The reservoir temperature remains constant throughout the oil well's life, further complicating the fluid flow dynamics (Shokrollahi, 2015). Adjustments in the gravity of residual oil are not required (Gaganis&Varotsis, 2016).

f) Implications and Future Directions

The results underscore the importance of accurate PVT analvsis for effective reservoir management. Understanding the dynamics of gas evolution, formation volume factor, and viscosity can significantly influence oil recovery strategies. Future research should consider advancements in PVT measurement techniques and methodologies that could enhance accuracy and efficiency. This could include integrating new technologies for real-time monitoring and analysis, which may lead to improved decisionmaking in reservoir management.

V. CONCLUSION AND RECOMMENDATION

a) Conclusion

This study conducted pressure, volume, and temperature (PVT) analyses of a black oil reservoir to determine its economic viability. PVT studies are essential as they enable reservoir engineers to predict and compute the probable hydrocarbon reserves available accurately.

Key findings indicate that the crude oil exhibits high viscosity, with an average absolute error (AAE) of 3.5% (0.035). Gas began evolving at 2000 psig, increasing as the pressure decreased. Notably, at a higher pressure of 4500 psig, the viscosity of black oil was measured at 0.54 cp, while at a lower pressure of 15 psig, it increased to 1.38 cp. This significant variation in viscosity with pressure suggests implications for the reservoir's productivity and economic worth, as higher viscosities can complicate extraction processes.

The observed gas evolution at 2000 psig is particularly relevant, indicating a threshold for gas

release that could affect reservoir management strategies. Understanding these dynamics helps in making informed decisions regarding development and extraction practices.

The findings underscore the importance of PVT studies in reservoir management and economic evaluations. Further studies are recommended for future research to validate these findings and explore additional parameters that could enhance our understanding of reservoir behaviours. Innovative approaches, such as advanced PVT measurement technologies and modelling techniques, could further improve the accuracy of these analyses and their implications for reservoir engineering.

In summary, this research contributes valuable insights into the characteristics of black oil reservoirs, providing a foundation for effective management and maximization of hydrocarbon recovery.

b) Recommendations

Based on this research and my personal opinion, the following recommendations can be made for the black oil PVT report analyzed in this research project.

- 1) The surface sampling method (surface recombination method) will yield а more representative sample of the total fluid regardless of the presence of free gas in the flow string because when free gas is present in the flow string at the point of subsurface sampling, a representative homogeneous immixture of total fluid will not be found, because when gas appears either static or moving column of oil the bottom home sample will usually be underestimated.
- 2) To check the quality of the sample, duplicate samples should always be taken if the reservoir contains a greater number of wells and is or has a high structural relief. Such duplicate samples should be obtained on several wells 4 to 8.
- 3) Laboratory result output samples (PVT reports) must always be checked against the reservoir's actual production pressure performance (Okoduwa, 2010).
- 4) To check the laboratory values by studying them and accompanying them with actual field production performance, several plots, such as a plot of reservoir pressure versus cumulative oil production, a plot of Cumulative fluid production and pressure drop, i.e. NP/DP VNP, and a plot of flowing pressure gradients versus depth, will all indicate a change in slope at bubble point pressure.
- 5) A reservoir simulation method should be used to regenerate the required PVT parameters for black oil, gas condensate, and other reservoirs before they are put into production.(Elkatatny and Mahmoud, 2018).
- 6) This project work required using standing correlations to validate the basic PVT parameters of

a black oil reservoir. Other correlations, such as Vasquez and Beggs, Glaso, or Marhran correlations, can also be applied.

References Références Referencias

- Ahmed T., (2016). "Equations of State and PVT Analysis – Applications for Improved Reservoir Modeling." (second ed.), Gulf Publishing, Cambridge, MA, US (2016).
- Shokrollahi, A., (2015). "On accurate determination of PVT properties in crude oil systems: committee machine intelligent system modelling approach." J. Taiwan Inst. Chem. Eng. (2015).
- Dessouky S.M. and El-hoshoudy A. N., (2018) "Application of PVT Calculations to Recombine Volatile Black Oil Surface Separator Samples To Obtain Subsurface Samples For Reservoir Studies."
- 4. El-hoshoudy A. N., (2019) "PVT PROPERTIES OF BLACK CRUDE OIL-A REVIEW."
- El-Hoshoudy A.N. &Desouky S.M., (2018).. "An empirical correlation for estimation of formation volume factor of gas condensate reservoirs at separator conditions." Petroleum & Petrochemical Engineering Journal. 2018;2(2):9[16]
- 6. El-Hoshoudy A.N., (2018). "Numerical prediction of oil formation volume factor at bubble point for black and volatile oil reservoirs using non Linear regression models." Petroleum & Petrochemical Engineering Journal.2018;2.
- Elkatatny, S. and Mahmoud, M., (2018). "Development of new correlations for the oil formation volume factor in oil reservoirs using artificial intelligent white box technique." Petroleum 2018, 4, 178–186.
- Gaganis V. &Varotsis N., (2016). "Identification of the Compositional Path Followed during Reservoir Simulation Improves the Accuracy and Accelerates the Phase Behavior Calculations." SPE Europec, Vienna, Austria (2016) May 30– June 2. SPE 180124.
- 9. Moradi B, et all (2013). "New oil formation volume factor empirical correlation for Middle East crude oils. International Journal of Petroleum and Geoscience Engineering(IJPGE);2013:12-23[89]
- Nojabaei and Johns, (2016). "Extrapolation of blackand volatile-oil fluid properties with application to immiscible/miscible gas injection. J. Nat. Gas Sci. Eng., 33 (2016), pp. 367-377.
- 11. Okoduwa I, Ikiensikimama S.(2010) "Bubble point pressure correlations for Niger Delta crude oils." In: Nigeria Annual International Conference and Exhibition; Society of Petroleum Engineers. 2010[96].
- 12. Oyedeko KF &Ulaeto UW (2011).. "Predicting the dead oil viscosity of reservoir fluids: A case study of

the Niger Delta." Journal of Energy Technology and Policy. 2011;3:1-7[100]

- S. Rafiee-Taghanaki et al (2013) ."Implementation of SVM framework to estimate PVT properties of reservoir oil." Fluid Phase Equil. (2013)
- Standing, M.B. (1947). "A pressure, volume, temperature, correlation for mixtures of California oils and Gases Drilling and Production Practice" pg. 275.
- Tower, B.F. (2002). Fundamental principles of reservoir Engineering, Henry L. Doherty Memorial Fund of ATME, SPE, Richardson, Texas, page 19-30.
- Zamani, H. et al., (2015). "Implementing ANFIS for prediction of reservoir oil solution gas-oil ratio." J. Nat. Gas Sci. Eng. 2015, 25, 325–334.



GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

New Ability for Analysis of the Focus Zone of the Crust Seismic Events

By Alexey G. Epiphansky

Abstract- The initial goal of this work was to improve the location algorithms used to determine the depth of crustal events. Eventually, it became apparent that we were incapable of determining the depth of what is required. The location problem has solutions based on Geiger methods. Iteration procedures are used to solve this mathematical task that is purely mathematical. The mean square residual is the criteria used to conclude the iteration procedure. The physical problem of estimating the origin location and impact of the following earthquake on surrounding environments has not been addressed by any of them. It's clear that the impact is dependent on radiation during seismic activity.

From the other side, the beginning of the seismic events is determined by the set of arrival times, which is the sole instrumental evidence of the process. So it is clear that having kinematic parameters, such as arrival times, is necessary to determine a dynamic solution. Sure, the seismic records are available for use.

Keywords: seismic events location, event depth, focal zone, seismic depth phases, rupture line, characteristic lines, sub focuses.

GJRE-J Classification: LCC: QE534.2



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New Ability for Analysis of the Focal Zone of the Crust Seismic Events

Alexey G. Epiphansky

Abstract- The initial goal of this work was to improve the location algorithms used to determine the depth of crustal events. Eventually, it became apparent that we were incapable of determining the depth of what is required. The location problem has solutions based on Geiger methods. Iteration procedures are used to solve this mathematical task that is purely mathematical. The mean square residual is the criteria used to conclude the iteration procedure. The physical problem of estimating the origin location and impact of the following earthquake on surrounding environments has not been addressed by any of them. It's clear that the impact is dependent on radiation during seismic activity.

From the other side, the beginning of the seismic events is determined by the set of arrival times, which is the sole instrumental evidence of the process. So it is clear that having kinematic parameters, such as arrival times, is necessary to determine a dynamic solution. Sure, the seismic records are available for use.

At this time, it has been recognized that a new algorithm is required to identify the location with the most seismic energy radiation. The first arrival times must be matched to this location. Secondly, the internal structure of a focus zone must be decomposed by seismic energy using the new algorithm. During the investigation it appears that travel time tables have self-organized structures.

These structures were called a "rupture line" which associates with the event itself and characteristics each of which associates with used seismic phases. In this work two seismic phases are used: phase P and phase pP. These structures became the basis of algorithms which are able to focus on any point that lies within the focus zone and translate dynamic parameters from seismic records into these points. Thus, formulated tasks are solved and the algorithms are derived. Some results demonstrate the data processing of the actual seismic events in conclusion of the article.

Keywords: seismic events location, event depth, focal zone, seismic depth phases, rupture line, characteristic lines, sub focuses.

I. INTRODUCTION

arthquake focus location procedures and its applications had appeared long before the XIX century. Automated procedures and wide-scale use of it were appearing in the middle of the XX century. So it may seem that we should know all about location procedures itself and Earth interior, nothing new can be found in this way.

Nevertheless, it turned out – something new may be found at hand. Detailed analysis showed that

new is hidden in the velocity structure of the crust and upper mantle. It comes from here into generalized seismic travel tables fluently.

To be honest, this requires time, power computers, digital seismic records and time synchronization of seismic recorders.

The work is based on data processing of seismic records obtained from different agencies. Most seismological investigations deal with particular seismic events. In our case we have analyzed the process of location itself, and try to generalize the results to have as comprehensive as possible valuable algorithms.

We had been searching common intermediate appearances of some dependencies of the time delaying from depths when such dependencies were found. The object of investigation was changed at that moment: instead of location procedures the model of crust seismic events became the object of investigation.

At the same time, we meet with disagreement: the result of seismic event location is a point. For the earthquake appearance it is required that in its sources were presented the movements of a big¹ mass of material with varying acceleration. That generates enough kinetic energy to produce an observed action as an earthquake. This point gives a start to changing the direction of the investigation. We began searching for a way to describe the focal zone model in terms of energy.

Now, we can talk about the tools we used in this investigation. At first, we were using a standard location algorithm. This work uses a modified Geiger algorithm of location ([Geiger, L., 1912]), supplemented with the simplex method ([Ge, M., 1995]; [Prugger, A., et al., 1989]).

Work carried out in a frame of investigation of the ability to elaborate automated determination of the core events depth. Nevertheless, we were trying to find the ability to work terms energy².

II. RUPTURE LINE

Geiger method permits finding the location of most seismic events if they have enough arrivals starting from an arbitrary hypocentre approach. But almost near

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¹ In the article [Bruno, J., 1968] it was shown that direct measurement of displacements in rupture zones are few cm per year. This smol displacement required the simultaneous movements of a big mass of material.

² Energy could not be associated with a point, only for volume of material it may be done.

the final point of the solution the convergence begane to decrease. To understand the reason that led to such behavior, the location algorithm was changed on the final steps. The Geiger method was changed by the simplex method which was combined with a fixed depth calculation procedure. This procedure consequently changes depth with fixed steps for each new hypocentre location.

The result showed that hypocentres were lining up to the chain. Analysis indicated that chan's links form a smooth line. This effect was observed for all processed events. This line is located in 4D space: three 3D space coordinates and time. But only two of four coordinates have significant meaning – depth and time. This is a common property for any set of first arrivals of the same seismic event. We named this effect "rupture line". It is not a line of rupture in reality. This line is the locus of hypocentres obtained by the location procedure.

Strictly speaking, a rupture line is a structure or object (from algorithmic points of view). An element of this structure involves several parameters. Each element corresponds to hypocentre location. Mathematically, it may be written as:

$$\mathcal{W}(h) = \{ w = w(t_0, \varphi, \lambda, h; \mathcal{R}) \}, \quad (1)$$

where w()- a function that determines parameters of the structure elements. First forth parameters determined hypocentre location. Fifth parameter \mathcal{R} is a mean square root residual (RMS). This parameter defines the quality of the location solution. We can write expressions for RMS as:

$$\mathcal{R}(\mathcal{E},h) = \frac{1}{(M-n)} \sqrt{\sum_{m=1}^{M} \tau_m^2(h)} \quad (2)$$

where $\mathcal{E} = (t_0, \varphi, \lambda)$ - epicentre parameters, h - a trail depth, τ_m - phase residual, m(m = 1, ..., M) - index of seismic phase, M - total phase number, n - number of independently defined parameters. Phase residual is:

$$\tau(r_m, h) = t_m - t_m^C(r_m, h) + \epsilon_m$$
(3)

where τ - phase residual dependent of epicentral distance r_m and trail depth; t_m -observed time arrival of phase m, $t^C(r_m, h)$ -calculated time arrival for phase m which is dependent from epicentral distance and depth and may be obtained from travel time tables. The last summand ϵ_m - presents uncertainty of measurement of m's time arrival. Uncertainty of the measurement should be present in expression of a phase residual, but it may be put to zero without loss of generality during formal expressions manipulations.

The calculated time arrival may written as $t_m^C(r_m, h) = t_0(h) + \gamma(r_m, h)$, where $t_0(h)$ - origin time, $\gamma(r_m, h)$ -a function to calculate time delaying by travel

$$t_0(h) = \langle (t_m^C - \gamma(r_m, h)) \rangle = \langle t_m^0(h) \rangle$$
(4)

where argument in last term $t_m^0(h)$ -is a phase origin time, the angle brackets means the operator taking the average of the argument. As usual, algorithms that use the Geiger method or simplex technique are fined a value of the origin time by averaging the middle term of expression (4). Expression (4) indicates dependencies between parameters from structures of different types – the first structure is a rupture line; next is discussed in the next section.

Fig. 1 presents the graphs of three coordinates of the rupture line - origin time (a), latitude (b) and longitude (c). Fourth coordinate - depth is a parameter (vertical axis). Two coordinates are parameters of the structure - origin time and depth. It means that any one of these parameters define location along this structure. The last indicates strong dependencies of these two parameters. That is vital for our further considerations. The presented result was obtained from the data processing of the event 2022.01.7 17:40:34 in China. It is essential that dependencies for space coordinates from depth are weak. This deviations from a straight vertical line originated by in homogeneity of media of propagation seismic waves and due to discrepancy Globe with ideal sphere form - deviation value in $1^{\circ} \cdot 10^{-5}$ (arc degree) corresponds to 1.19 m.

III. CHARACTERISTICS

The last term in expression (4) does not contain parameters of a rupture line. At the same time, the first term is rupture line parameters only.

This leads us to mind: maybe we have another linear structure similar but differs from the rupture line?

If in expression (4) we have structure in the left side and averaging operator of set of structure parameters in right, it quickly suggests that structures in argument in the right side have the similar behaviour to the structure in the left of (4).

For time arrivals can be written following expression:

$$t_m = t_0(h) + \gamma(r_m, h,)$$
. (5)

In the previous investigation ³ was found: if $t_0(h) \in \mathcal{W}$ than $t_m = const$ for any h.

This assertion should be proven. But travel time tables obtained experimentally. So proving shall be based on comparing the results of data processing.

³ It was the same investigation where we met with the appearance of a rupture line structure.

Let us write the expression:

$$\mathcal{X}_{m} = \{ t_{m} = t_{0}(h) + \gamma(r_{m}, h) \mid 0 \le h < \Delta H \mid; t_{0}(h) \in \mathcal{W} \}$$
(6)

where m = (1, ..., M) is the number of the seismic records, ΔH - is a thickness of crust and upper mantle;

The expression (6) defines a mathematical set; let's call it a phase characteristic. Term phase means that we have such a set of t_m for each of the phases we are mentioned in the article. The set \mathcal{X}_m is similar to rupture line structure. The difference is that \mathcal{W} contains information from all arrival of the event, when each characteristic is connected only with one arrival.

Another similarity is that a characteristic element consists not only of parameter t_m , but of the following parameters $(t_m^0, h; t_m, a_m) \in \mathcal{X}_m$, where t_m^0 - a phase origin time, h - the depth along the characteristic, t_m - is arrival time, a_m - arrivals amplitude. The parameter t_m defines \mathcal{X}_m uniquely due to it being constant within characteristic. The params t_m^0 and h defines location along characteristic.

From (5), we can write

$$t_m^0(h) = t_m - \gamma(r_m, h)$$
. (7)

This expression consists of absolute time in terms of $t_m^0(r_m, h)$ and t_m . To simplify comparing, we subtract $t_m^0(r, h)_{h=0}$ from both these terms (or from the left and right side of the expression (7)). Such a way, we got relative time expressions. It will be used later.

Now, we can compare the relative phase origin time values with the relative origin time values along the rupture line. We will be presented on a graph below the relative values of parameters only. We will be implied as a subtrahend parameter value on zero depth, if the opposite does not indicate.

Fig. 2 presente the dependence from depth of the origin time on a characteristic $t_m^0(r_m, h)$. Fig. 2.a are presented graphs for four epicentral distances. The epicentral distances are: line $1 - r_m = 25^{\circ}$, line $2 - r_m = 50^{\circ}$, line $3 - r_m = 75^{\circ}$, line $4 - r_m = 100^{\circ}$.

Fig. 2.b are presented graphs for the same epicentral distances, but as a subtrahend was taken the origin time at depth $h^f = 12.5 \ km$. It is demonstrated that characteristics cross in one point corresponds to the focus depth. Fig. 2.c. presented comparing the dependence of a depth of the origin time on the characteristics and the origin time on the rupture time. Line 1 is the characteristic origin time with $r_m = 25^{\circ}$, line 2 is the characteristic origin time with $r_m = 100^{\circ}$; line 3 is the rupture line origin time. The results obtained for the event 2022-01-07 17:45:34 in China.

We can see on Fig. 2 that slope of a characteristic is changing with a changing of epicentral distance. Fig. 3 demonstrates in 3D projection two arguments function $\delta t(r,h) = t_0^{\mathcal{X}}(r,h) - t_0^{\mathcal{X}}(r,0) = (\gamma(r,0) - \gamma(r,h))$ which are obtained from (7) by eliminating absolute time.

We can see that the region of available epicentral distances splits into some zones. Two of them have smooth dependence on epicentral distances. This requires certain restrictions during the picking up of the seismic stations for data processing.

IV. LOCAL UNIT FOR MEASUREMENT OF ENERGY SIMILAR VALUES

The value of \mathcal{R} calculated along the rupture line might have not a minimum for some events in a reasonable interval of the depth. This does not mean that (2) is not working. It means that uncertainty of residuals in (3) in dependencies of the depth is large. Another reason may be unsuccessful selection of seismic stations. We will discuss this later. In this work we are very wide using this criteria \mathcal{R} for location procedure with fixed depth values. Coordinate location procedure finds out the minimum of value of \mathcal{R} always.

In this work, we will not concentrate on the problem of why the above might happen (see also [Dmitry Storchak, 2011] and [Engdahl, E.R., et al., 1998]). This is a well-known fact. This work suggests different criteria for the final solution. The suggestion is based on using a physical indicator. Such an indicator may be seismic energy (or value with similar properties) emission from the focal zone.

The final hypocentre is located on the rupture line in the point where seismic energy reaches maximal value. Actually, the rupture line is a locus of points of minimum expression (2) with fixed depth. This is coincidental with traditional location procedures. We are refusing to search the minimum of (2) by the depth and suggested searching the maximum of the energy radiations along the rupture line.

As an energy similar object, we are choosing the "amplitude parameter" or for short AmP. Its expression is

$$AmP = \frac{1}{M} \sum_{m=1}^{M} \left(\frac{1}{K} \sum_{k=1}^{K} \rho_m^2(f_k) \cdot f_k^2 \cdot \delta f \right)$$
(8)

where $\rho_m(f_k)$ - spectral amplitude, f_k - spectral frequency, δf - sampling interval, k = (1, ..., K)-frequency index, K - one side frequencies number of Fourier transforming (for positive and negative frequencies, it has the same value (see Appendix A)); m = (1, ..., M)- phase index and M- number of seismic records. *AmP* is calculated separately for each phase.

AmP has physical dimension $\left[\frac{m^2/S^3}{S^2} \cdot \frac{1}{S}\right]$. If *AmP* value multiply to granite density $\left(\rho = 2600 \frac{kg}{m^3}\right)$ on the Earth's surface, we will got dimension $\left[\frac{Nm \cdot \frac{1}{m^3S}}{m^3S}\right]$. So, the seismic radiation energy in Joulies may be obtained by integration over the volume of the focus zone (this requires knowing how the energy radiation is distributed over the focal zone) and over the time of focus zone activity.

Desired algorithm was created. The algorithm is included another algorithm to calculate coherence in every point of the focus zone⁴. The last algorithm is a central part of described development. The vital ability of that algorithm is that it permits defining the main part of the spectral window. The main part is defined by the maximum coherence value. Appendix A describes it.

The AmP physical dimension is $\begin{bmatrix} m^2 \\ S^2 \end{bmatrix}$. It is not an energy yet, but relations of two such values give us the same result as a relation of energy values. AmPmay be used for comparing relation values insead energy in the frame of one event.

The first problem formulated in the frame of this work is a determination of the depth of crust events. The depth of the event may be determined by searching the maximum of seismic radiation along the rupture line. Unfortunately, we have an impenetrable obstacle – amplitude along characteristic is constant.

V. Depth Phase *pp*

The determination of the event depth depends on the answer to the question: what is the depth of the seismic event? Traditionally, this parameter was taken from the mathematical solution of a location task. Unfortunately, this determination of term depth ignores physical aspects of earthquake phenomena.

This work suggested using depth value which corresponds to maximal radiation of seismic energy along rupture line. Considering, that amplitude along P characteristics are a constant it is possible to use another phase. The depth phase pP may be used instead of the P phase. pP phase has the same focus impulse⁵ as a phase P.

Fig. 4 shows the graphs of pP characteristics phase origin time in dependency of depth - continues lines and from epicentral distances – separated lines. The essential property of pP characteristics is that its derivative of phase origin time by depth is negative while P phase origin time derivative is positive. These two types of characteristics are crossing in a compact area of 4D space. Later, we will examine this phenomenon in detail.

Before the next step, we rewrite expression (7) to make it clearer to which phase we mean

$$t_m^{0,pn}(h) = t_m^{pn} - \gamma^{pn}(r_m, h),$$
 (7)

where pn is the seismic phase name: P or pP.

The result of the location procedure is presented in Fig. 5. This result was obtained from processing of the data of the event 2022-01-07 17:45:34 in China. That is an example of using both seismic phases P and pP. Fig. 5 presents three graphs of AmP: curve 1 - graph of $AmP^{(P)}$, curve 2- graph of $AmP^{(P)}$, curve 3 - graph of expression.

$$A_n = AmP_n^{(pP)} \cdot \left(\sum_{n=1}^N AmP_n^{(P)} \middle/ \sum_{n=1}^N AmP_n^{(pP)}\right)$$
(9)

where n = (1, .., N) – index along rupture line and N – number of points where AmP was calculated; the value A_n is the reproduction of the values of $AmP^{(P)}$ by scaling $AmP^{(pP)}$. Thus, we are taking into account the difference in amplitude of vertical components ⁶ of a direct wave (P phase) and a reflected wave (pP phase). Thus, we are bypath restrictions connected with the property of the P characteristics. Expression (9) presents the algorithm of amplitude coordinations.

The maximum on the curves 1 and 3 define depth value $h = 14.75 \ km$, while USGS defined depth for this event as $13 \ km$.

So, we see that developed algorithms are working. Let us now clarify how it works.

VI. The Solution Space and Frame Reference

The schematic chart in Fig. 6 shows the collaboration of two dedicated seismic phases. First, we consider the frame reference of our solution. It is not a pure physical frame reference. 3D physical space will stay without changes. The fourth axis is a time. Chart in Fig. 6 is a slice of 4D space by a time-depth plane⁷. Line (*A*, *B*) and its continuation is the time axis. The line (*A*, *C*) and its continuation is *P* characteristic; the line (*B*, *C*) and its continuation is *pP* characteristic. It is drawn only one pair of characteristics belonging to the same record: we suggest that each recorder registered a pair of arrivals⁸ which can be detected as phases *P* and *pP*. We are assuming that two seismic phases always exist

⁴ The coherence is the normalized module of the complex sum of spectrum phases of the Fourier transforming of the focus impulses while spectrum amplitudes are ignored.

⁵ The term focus impulse is applied to a displacement or to an energy parameter. The meaning of this term is the same: one side finite smooth function.

⁶ We are using vertical components of the seismic records only.

⁷ The rupture line is a 4D curve. The deviations from the strict vertical line of the latitude and longitude values are relatively small. It can neglect these.

⁸ The recorder is registered for both seismic phases, but the standard detector does not detect both.

and therefore two characteristics exist too. The point C is a place where these two characteristics are crossing. According to the property of characteristics, the AmP along each of them are constant. What is the AmP value in point C? It looks like we have a contradiction.

In reality, The source is located at the point C. The seismic radiation reaches the recorders with different amplitudes due to differences of the travel ways including radiation pattern. Hence, AmP^P does not equal to AmP^{pP} .

There are two solutions to the mentioned problem that are presented in this work. One was demonstrated in connection with location procedure. Second will be considered later.

Each element of characteristics contains both parameters: t_m^0 and t_m . First is the parameter which defines location along characteristic, second is a constant along characteristic. Value of event origin time t_0 is the averaging value of all characteristic parameters t_m^0 (m = 1, ..., M).

Let us segment (A, C) or (B, C) are the generalized characteristics: point A will be an origin time of phase P; point B will be an origin time of phase pP. Point C is a place of crossing of both characteristics.

Let us introduce the value h^f as a fixed value of the focus depth. Another meaning of the parameter h^f is a focus depth. This (A, C) segment may be a characteristic of phase P or a rupture line.

In this case, $t_m^0(h^f) \equiv t_0(h^f) \forall m = (1, ..., M)$ It means all characteristics and the rupture line are crossing at the point $(t_0(h^f), h^f)$ in 4D space.

Let us named of abscissa axis (time axis) as τ . In this case, we can write for point A expression $\tau_A = t_A^{0,P}(h)_{h=0} - t_0^P(h)_{h=0}$. The same expression we can write for point $B \tau_B = t_B^{0,PP}(h)_{h=0} - t_0^{PP}(h)_{h=0}$. According to (7) and to the fact that $\gamma^P(r,h)_{h=0} \equiv \gamma^{PP}(r,h)_{h=0}$ we have $\tau_A(h)_{h=0} \equiv \tau_B(h)_{h=0}$ If $h^f = 0$ then $\tau_A = \tau_B$. With depth increase the point B will be moved from τ_A point to the right.

We can write for τ next: $\tau_A = \gamma^P(h) - \gamma^P(h)_{h=0} < 0$ and $\tau_B = \gamma^{PP}(h) - \gamma^{PP}(h)_{h=0} > 0$. It easy to see that the distance of time between values τ_B and τ_A for depth $h = h^f$ is

$$\tau_B - \tau_A = \gamma^{pP}(h^f) - \gamma^P(h^f) \,. \tag{10}$$

The expression (10) is essential for our following consideration. We can formally use (10) to define the depth at the point *C* by the difference between the time τ_A and τ_B

The solution frame reference consists of the 3D physical space and relative time.

VII. Applying Derived Mathematical Instrument for Investigation of the Seismic Events Focal Zone

This work was intended to improve depth location only. Eventually, we understood that our focus model should be improved too. Above, we described the procedure of determining events depth by applying amplitude parameters. The expression (9) converts the value of the $AmP^{pP}(h)$ into a AmP(h). The last corresponds to the intensity of P phase. Thus, the new location algorithm was preserved to be close to the traditional one. Graphs on Fig. 5 show the level of seismic radiations along the rupture line. The last was obtained by data processing of an event's records.

The next step was an attempt to apply an amplitude parameter for generalizing the station's seismic records. It shows the relative radiation intensity for active (coseismic) time period. It shows that the curve of the seismic activity has one maximum impulse and several impulses of less intensity. The less intensity impulses are the appearance of an internal sub-focus. The last achievement is ability to plot distribution of the intensity of inner sub-focuses. All this expansion was derived on the basis of mathematics described above.

The basis of algorithms is described above triangle A, B, C (Fig. 6). The line (A, C) is a part of the rupture line. Rupture line depends on the event's origin time, which depends on arrival times. If we forget about arrival times and will be changing origin time our geometrical construction that involves M triangles will be moving along a time axis as a single object (m is a number of recorders). In this case, inverse recalculations of new arrival times give the ability to take the amplitude parameters for new origin time. Thus, we can move along the time axis. The 3D space movement may be done by similar procedure.

It is possible to use all properties of the rupture line and all characteristics in the new time and space position. We can do it due to the fact that the parameters of our geometrical construction depend on the permanent data only.

Let us repeat the vital property: the value of parameters of the characteristic element are constant. According to this, the value of the AmP parameter on characteristic for depth zero will be translated to point *C*. We considered it early.

At the point C we have two AmP values. The problem is: how is it possible to agree on these two values? We used the following expression:

$$A = \frac{\sum_{m=1}^{M} \left(AmP_m^P \cdot AmP_m^{pP}\right)}{\sum_{m=1}^{M} \left(AmP_m^P + 0.25AmP_m^{pP}\right)} , \quad (11)$$

where A- resulting amplitude parameter value for each point on choosing subspace, m = (1, ..., M) - index of the seismic records, M-number of records. That is another variant of the algorithm of amplitude coordinations. First was presented as expression(9).

We point out that expression (11) gives out A in relative values. Usually, nobody uses energy in seismology, but it uses magnitudes. The last is relative value too. So it is not a problem to convert AmP to correspondent magnitude. In future we are planning for practical usage of such conversation. At the moment it is not important.

VIII. AN ADDITIONAL PART OF RESIDUAL VALUE DUE TO CHARACTERISTICS Dependences

The characteristics are crossing (Fif. 2.b) at one point if the uncertainty is zero. If $\epsilon \neq 0$ then correspondent characteristic will be shifted. This leads to shifting a cross point of some characteristics. As a result, the non zero value of ϵ influences indirectly onto a RMSI value of the event.

These uncertainty values are playing a complicated role in the averaging operator. Any error in arrival time causes characteristic's disagreement - error in arrival time shifts characteristic cross point along the rupture line. Instead of one cross point we have several shifts by depth. It is not possible to eliminate but it needs to be known.

The point of the crossing of the pair of characteristics are dependents from time and depth as it was shown above. Moreover, characteristics have different slopes by time (or by depth). This slope is dependent from the epicenter distances.

The Fig. 7 demonstrates the maximal of a deviation. As we can see, the deviation may reach seconds: the difference between $t_m^{0,(P)}(r,h)_{r=25,h=0}$ and $t_m^{0,(P)}(r,h)_{r=175,h=0}$ may reach 0.8 sec. For phase pP it is near the same. This is corresponds to the focus depth $h = 40 \ km$. These estimations were made when the set of stations was restricted by teleseismic distances.

IX. Examples of Actual Data Processing BY THE DERIVED MATHEMATICAL TOOLS

It is commonplace to treat a model of the focus zone as a set of sub-focuses. The evidence of each sub-focu is a focus impulse that is present in the seismic records. We are not meaning the displacements in the source. We are talking about evidence of the rise of seismic energy.

The impulse has two markable points in regard to Fig. 6: the beginning is the τ_A mark and an amplitude maximum the τ_B . Why are we connecting the maximum of the radiation with point B on Fig. 6? Fig. 5 may clarify this.

Fig. 8 shows a plot for the event 2022-01-07 17:45:34 in China. The curve of Fig. 8 is AmP(t)generalized parameter calculated for h = 0 along the timeline in time interval t = (-5, ..., 20) sec. (Term generalized means: $AmP(t) = \frac{1}{M} (\sum_{m=1}^{M} AmP_m^P(t,h))_{h=0}$, where *M*-number of used seismic records.)

This plot illustrates what was said above. There is one global pulse in general and several local pulses with small amplitudes. The graphs shown on Fig. 8 result from applying an algorithm derived from expression (8). And again, we can see one global pulse and several local pulses of sub-focuses (see Fig. 5). Fig. 5 plots were drawn along a rupture line. The Fig. 8 graph is very close to the graph on Fig. 5. The difference is in abscise units: one has a time and another depth.

The active process begins before the first braking pickup algorithm registered first arrivals. Another feature is the presence of several local maxima on both graphs. We can treat that as evidence of several focuses presented in the focal zone.

In this work, we are demonstrating the results of processing two seismic events:

- 1. 2022-01-07 17:45:34 in China and
- 2024-01-22 18:09:09 Border of Kyrgyzstan & China. 2.

Additional information about these events is aiven in Table 1.

First event has a crust origin and is a moderately normal seismic event without special features. We are using it as a coaching event. Fig. 5, 8 and 9 show some abilities for analysis of evaluation of this event. Fig. 5 shows the results of location data processing. Fig. 8 presents an generalized AmPparameter in time interval t = (-5, ..., 20) sec. Fig. 9 presentes a map on a horizontal slice that consists of the origin vicinity. Map demonstrates the distributions of seismic activity. It draws attention to itself that origin consists of few ruptures.

Second event has an origin depth at the bottom of crust (h = 42.7 km). Fig. 10.a presentes the result of location data processing. It is interesting that USGS gave a depth of 13 km for both these events. It looks like this depth was fixed during the location procedure. Other features: seismic energy began to emit before first arrival times were registered (see Fig. 10.b). It is significant in seismology when we are observing some kind of precursor.

Fig. 11 presents two-dimensional slices of 3D space containing the origin. One slice Fig. 11.a presents a map of the seismic activity in the origin vicinity.

Moreover, we can trace several seconds of seismic activity before origin time on the vertical slices in coordinates (R, h) in backward time perspective. Axis R is a segment of arc on the surface (line (A, B) on map Fig.11. a), the R unit is arc degree. Axis h is depth in km. All what shows on Fig. 11 for demonstration only. It pays attention that all vertical slices correspond to times before zero time on graph Fig. 11.b. This picture series shows the rising of the seismic activity in the origin vicinity from mantle to up.

In general, Investigation of particular events does not aim for this work. It is a topic for another article.

It is required to emphasize some differences in final results of events location. Especially, t_0 strongly depends from the depth according to the rupture line properties. Coordinates have less dependents but these dependencies are present.

Acknowledgment

This work and investigation itself could not be successful without the help of Dr. Irina Gabsatarova and

Dr. Inessa Socolova. I express my deep appreciation to their patient, attention during our discussions and for support with data picupping.

Seismic data was uploaded throw web-services iIRIS included next seismic networks (http://ds.iris.edu/ mda): (1) II Global Seismograph Network – IRIS/IDA (Scripps Institution of Oceanography); (2) IU Global Seismograph Network IRIS/GSN (Albuquerque Seismological Laboratory/USGS).

I appreciate the ability to work for the Union Geophysical Survey of RAS. I express my appreciation to all my colleagues who help me in this long investigation.

Table 1

Time	Location	Depth	Depth by source	М	Region & Source
2022-01-07 17:45:31.832	$37.573^{\circ}N \ 101.435^{\circ}E$	$14.62 \ km$	$13 \ km$	6.6	Northern Qinghai, China. Source: USGS
2024-01-22 18:09:09.223	$41.033^{\circ}N$ 78.905°E	$42.75 \ km$	$13 \ km$	7	Border of Kyrgyzstan & China. Source: USGS

Appendix A

Coherence Level and Amplitude Parameter

Seismic records coexist with all of the seismic signals over the whole planet's crust. The difference is in amplitudes of signals. By shape all seismic signals are similar. To separate signals from different sources one can use differences in terms "similar" and "the same". It means that signal amplitudes are ignored.

Seismic signals differ by length and amplitude increasing in time. Two of these features are enough to separate different signal sources. This is used in microseismic investigations mostly. The method is based on the "comparing operator" applied to spectral phases (with unknown amplitude) of Fourier transformation of the signal's pulse. A comparing operator is applied for all available seismic records – stacking method. This may presents by expression

$$\Phi = \frac{1}{K} \sum_{k=1}^{K} \left(\frac{\operatorname{mod}(\sum_{m=1}^{M} e^{i\varphi_m(f_k)} w_m)}{\sum_{m=1}^{M} w_m} \right)$$

where $\varphi_m(f_k)$ - spectral phase on frequency f_k , w_m - weight function, K - one side frequencies numbers of Fourier transformation, M - number of seismic records. Algorithm is using discrete Fourier transform.

Some clarification about "one side frequency number". Obviously, the Fourier transformation is symmetrical operator in range $-\infty \leq f \geq \infty$. Fortunately there were several rules (William T. Vetterling, at. al., 1988) that permitted operation of computation to

bring a simple one side numerical operator. ([Ge, M., 1995]; [Prugger, A., et al., 1989]). On the basis of it is the fact that the impulse of a seismic source is one side finite in time smooth function.

Value Φ can be used for checking whether two or more seismic impulses coincide. It may evidence with higher degree of probability that two seismic phases Pand pP were emitted by one source. The algorithm derived from Φ expression may operate with signals which amplitudes less than noise level.

For each seismic event frequency-time window may be determined where the coherence level reaches the maximum. Time sampling period is critical for frequency-time window parameters.

References Références Referencias

- 1. Brune, J. (1968). Seismic Moment, Seismicity, and Rate of Slip along Major Fault Zones. *J. Geophys. Res.*, v.73 v. 2, pp. 777 - 784.
- Engdahl, E.R., van der Hilst, R. & Buland, R., (1998). Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, *Bull. Siesm. Soc. Am.*, v.88, pp. 722-743.
- Ge, M. (1995). Comment on "Microearthquake location: a non-linear approach that makes use of a Simplex stepping procedure" by A. Prugger and D. Gendzwell, *Bull. Seism. Soc. Am.* 85, pp. 375-377.
- 4. Geiger, L. (1912). Probability method for the determination of earthquake epicentres from the arrival time only, Bull. St. Louis. Univ. 8, pp. 60-71.

- Gendzwill, D. and A. Prugger (1989). Algorithms for micro-earthquake location, in Proc. 4th Conf. Acoustic emission/Microseismic Activity in Geologic Structures, Trans Tech. Publications, Clausthal-Zellerfeld, Germany, 601-605.
- Global Seismograph Network IRIS/IDA // International Federation of Digital Seismograph Networks [Site]. – DOI: 10.7914/SN/II (date of request 23.01.2024).
- Global Seismograph Network (GSN IRIS/USGS) // International Federation of Digital Seismograph Networks [Site]. – DOI: 10.7914/SN/IU (date of request 23.01.2024).
- 8. Murphy, J.R. & Barker, B.W., (2006). Improved focal-depth determination through automated

determination of seismic depth phases pP and sP, *Bull. Seism. Soc. Am.*, v.96, 1213-1229.

- William T. Vetterling, Brian P. Flannery, William H. Press, Saul Teukolsky, (1988) Numerical Recipes, The Art of Scientific Computing, Cambridge University Press, pp. 818.
- Prugger, A. and D. Gendzwill (1989). Microearthquake location: a non-linear approach that makes use of a Simplex stepping procedure, *Bull. Seism. Soc. Am.* 78, pp. 799-815
- 11. Dmitry Storchak, (2011). Improved location procedures at the International Seismological Centre, *Geophysical Journal International*, 186, pp. 1220-1244.



Fig. 1: Rupture line example for event 2022-01-07 17:45:34 in China. This is not a real rupture on this line, this is the geometrical places (locus) hypocentre coordinates in dependence of depth. Each hypocentre is calculated for a fixed depth. Each coordinate (except depth) is plotted as a difference of its value on depth and its value on the zero depth: (a) - origin time coordinate values, (b) - latitude values, (c) - longitude values. Depth range – from zero up to 50km.



Fig. 2: Examples of graphs of P characteristics origin time $t_0^{\mathcal{X}}(r, h)$ and rupture line origin time $t_0^{\mathcal{W}}(h)$. Plot (a) presents four graphs of $t_0^{\mathcal{X}}(r, h)$ at four epicentral distances: (1) $r = 25 \ degr.$, (2) $r = 50 \ degr.$, (3) $r = 75 \ degr.$, (4) $r = 100 \ degr.$ and focus depth $h^f = 0.0 \ km$. Plot (b) presents four graphs of $t_0^{\mathcal{X}}(r, h)$ at four epicentral distances as it was on plot (a), but for focus depth $h^f = 12.5 \ km$. Last plot (c) presents two P characteristics origin times $t_0^{\mathcal{X}}(r, h)$ at the distances: $r = 25 \ degr.$ line 1, $r = 100 \ degr.$ line 2, and graph of origin time of the rupture line 3. The rupture line is the processing results of the event 2022-01-07 17:45:34 in China. (h^f is some fixed depth).



Fig. 3: 3D projection of two dimensional function $t(r,h) = (\gamma^P(r,h) - \gamma^P(r,0))$ which is a difference of $t_m^0(r,h)$ and $t_m(r,h)_{h=0}$, where m = index over epicentral distances. The plot is drawn for argument value intervals: a - $r = (2, ..., 175)^\circ$, h = (0, ..., 50)km, b - $r = (0, ..., 35)^\circ$, h = (0, ..., 50)km. There are easy to see different zones distributed by epicentral distances: first - local zone, second - regional zone, third - transmission zone and fourth - teleseismic zone. The travel time table for the P phase has one degree gap.



Fig. 4: Examples of graphs of pP characteristics origin time $t_0^{\mathcal{X}}(r,h)$. Epicentral distances are the same as on fig. 2.



Fig. 5: Example of location data processing of the event 2022-01-07 17:45:34 in China. This presents two graphs of values of the amplitude parameters : 1-phase P, 2-phase pP; third graph plotted for value obtained by expression (9) – first algorithm of amplitude coordinations.



Fig. 6: Schematic chart of collaborations of pairs of the seismic phases: points A and B are situated on the time axis, segments (A, C) and (B, C) and its continuations are characteristics. The consideration is in the text.



Fig. 7: Deviations of time at the crossing points of P and pP characteristics due to epicentral distances. 1-P characteristic for $r = 25^{\circ}$, 2 - P characteristic for $r = 175^{\circ}$, 3 - pP characteristic for $r = 25^{\circ}$, 4 - pP characteristic for $r = 175^{\circ}$. Zero on time axis corresponds to origin time, values on time axis are differences between phase origin time on depth zero and $t_0^{\mathcal{W}}(h)_{h=hf}$ which is the origin time on the rupture line. Crossing point corresponds to depth $h^f = 40.0 \ km$.



Fig. 8: (left) Graph of the generalized AmP parameter obtained from data processing of event 2022-01-07 17:45:34 in China. The time interval t = (-5, ..., 20) sec; zero of the time axis corresponds to $t_0^{\mathcal{W}}(h)_{h=0}$.

Fig. 9: (right) Map of seismic activity at the depth of origin n = 14.7 km. Units along the axis are arc degrees.



Fig. 10: Example of the results of location data processing of the event 2024-01-22 18:09:09 border of Kyrgyzstan and China: a -three graph which are used for depth determination: line (1) parameter $AmP^{P}(W)$, line (2) parameter $AmP^{pP}(W)$, line (3) A_k - (pP to P)- -translated parameter(9); b-graph of the averaged AmP parameter in time interval t = (-10, ..., 60) sec; zero of the time axis corresponds to $t_0^W(h)_{h=0}$.





Fig. 11: Examples of focus zone interior analysis; event 2024-01-22 18:09:09 border of Kyrgyzstan and China: map of seismic activity on the origin depth (a), and series of the vertical slices hose horizontal cut given on map (a) as a (A, B) line; series presented for times: b- $t_p = 0 \sec$, c- $t_p = -1 \sec$, d- $t_p = -2 \sec$ and e- $t_p = -5 \sec$, f - $t_p = -7.5 \sec$, where t_p precursor time before $t_0^{\mathcal{W}}_{h=0}$. Time corresponds to the time axis on Fig.10.b. These figures were plotted by using the (11) algorithm of amplitude coordinations.





GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: J GENERAL ENGINEERING Volume 24 Issue 1 Version 1.0 Year 2024 Type: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Modeling the Constant Composition Expansion Test of Black Oil using Pressure, Volume, and Temperature (PVT) Calculations

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Abstract- The black oil pressure, volume, and temperature (PVT) properties of well X were measured in the laboratory in a PT cell with subsurface and surface recombination samples. Four sets of black oil samples were collected for the analysis. The black oil standard test is a constant composition expansion test (CCE) separator flash test for volatile oils and rich oil gas condensate and a constant volume depletion test (CVD). The PVT analysis was carried out at Reservoir Fluid Laboratory, Port Harcourt. Oil samples were collected from the Q oil field. The PVT analysis results were correlated to validate the bubble point pressure (P_b), oil isothermal combustibility, (C_o), oil formation volume factor (B_o), and the oil viscosity (μ_o). The PVT report gives P_o = 2000 psi while the standing correlation gives P_b = 1934.271 psi a difference of 65.7 psi, i.e. 3.3% and solution gas/oil ratio 647.3 SCF/STB while the standing correlation gives 671.03 SCF/STB a difference of 3.5%, oil formation volume factor (B_o) of 1.456 res. Bbl/STB while standing correlations give (B_o) of 1.0675 res bbl/STB a difference of 3.6%.

Keywords: isothermal pressure, volume, temperature, constant composition expansion, black oil. GJRE-J Classification: LCC: TN871.2



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Abstract- The black oil pressure, volume, and temperature (PVT) properties of well X were measured in the laboratory in a PT cell with subsurface and surface recombination samples. Four sets of black oil samples were collected for the analysis. The black oil standard test is a constant composition expansion test (CCE) separator flash test for volatile oils and rich oil gas condensate and a constant volume depletion test (CVD). The PVT analysis was carried out at Reservoir Fluid Laboratory, Port Harcourt. Oil samples were collected from the Q oil field. The PVT analysis results were correlated to validate the bubble point pressure (P_b), oil isothermal combustibility, (C_o), oil formation volume factor (B_o), and the oil viscosity (μ_o). The PVT report gives $P_o = 2000$ psi while the standing correlation gives $P_b = 1934.271$ psi a difference of 65.7 psi, i.e. 3.3% and solution gas/oil ratio 647.3 SCF/STB while the standing correlation gives 671.03 SCF/STB a difference of 3.5%, oil formation volume factor (B_o) of 1.456 res. Bbl/STB while standing correlations give (B_o) of 1.0675 res bbl/STB a difference of 3.6%. The isothermal compressibility of the oil ranges from $10.12 \times 10^{-6} \text{ psi}^{-1}$ at P < P_b (at 4500 psi) to 4.1309 x 10¹⁸ cp at 15 psi. The conclusion is that Gas began evolving at 2000 psig and increased as the pressure decreased. Also, it was noticed that at high pressure of 4500 psig the black oil viscosity was as low as 0.54 cp while at a lower pressure of 15 psiag the viscosity recorded was 1.38 cp. The crude is of high viscosity, with an average absolute error = 3.5% (0.035). The reservoir contains heavy crude oil with an API rating of 30.

Keywords: isothermal pressure, volume, temperature, constant composition expansion, black oil.

I. INTRODUCTION

uring the development of oil and gas fields, the fluid produced is subjected to several conditions. As they travel from the reservoir, up to the pipelines, and then through surface facilities, the system's pressure, and temperature change (Cosse, 1993). Along this process, the fluid composition, oil and gas volumes, and fluid properties such as density and viscosity will also vary.

To study how these volumetric changes will occur, several laboratory experiments are routinely conducted with reservoir oil samples in a PVT cell, reproducing the conditions that the fluids are subjected to during production (Whitson, 1981). The most common PVT test performed to characterize this reservoir fluid is constant composition Expansion. Petroleum (an equivalent term is crude oil) is a complex mixture consisting predominantly of hydrocarbons and containing sulfur, nitrogen, oxygen, and helium as minor constituents. The physical and chemical properties of crude oils vary considerably and depend on the concentration of the various types of hydrocarbons and minor constituents present (Cosse, 1993). Crude oil reservoirs are classified according to initial reservoir pressure into the following categories:

- 1) Under a saturated oil reservoir; in which initial reservoir pressure is greater than the bubble point pressure of reservoir fluid
- Saturated oil reservoir; in which initial reservoir pressure is equal to the bubble point pressure of reservoir fluid
- 3) Gas-cap reservoir; in which initial reservoir pressure is below the bubble point pressure of

A reservoir fluid, so reservoir is termed a gascap or two-phase reservoir since the gas or vapor phase is underlain by an oil phase. Petroleum hydrocarbons exist as gaseous or liquid phases depending on reservoir temperature. If it is higher than the critical temperature of the fluid, the reservoir fluid is gas (Whitson, 1981). Otherwise, the reservoir fluid is oil. The black oil reservoir is considered as one of the most precious reservoir fluids. It constitutes many oil reservoirs and exists in every basin. An accurate description of the physical properties of crude oils is of considerable importance in the fields of both applied and theoretical science and, especially, in the solution of petroleum reservoir engineering problems. Some of these physical properties are of primary interest in petroleum engineering studies and detected through PVT tests which aim to determine reservoir fluid behavior

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at simulated reservoir conditions. Data on these fluid properties is usually determined by the laboratory (Vasquez and Beggs, 1987).

Experiments were performed on samples of actual reservoir fluids. In the absence

For experimentally measured properties of crude oils, it is necessary for the petroleum engineer to determine the properties from empirically derived correlations. However, correlations are approximations and may be useful only in regional geological provinces.

Crude oils cover a wide range of physical properties and chemical compositions and are classified into black oils and near-critical or volatile-oils depending on their phase behavior (Moses, 1986).

The aims and objectives of this research work is to validate PVT parameters in a saturated black oil reservoir using Correlation. This research work will cover basic PVT parameters such as oil formation volume factor (B_o), solution gas/oil ratio (R_{so}), oil compressibility factor (Co), Oil viscosity (μ_o), and liquid/gas ratio of vapour phase (RV) (Tariq et al., 2021).

This research work will not cover the general PVT report as in analysis of constant composition expansion test (CCE).

Oil prospecting is a high-risk business and as such thorough investment decisions must be based on quantifiable and verifiable facts. PVT analysis is a tool that helps bring to the fore the likelihood of recoverable hydrocarbon fluids in a reservoir before proper capital mobilization and infrastructure planning can be made for the reservoir (Hemmati, 2016). The final investment decision is needed for any oil reservoir development to commence but this decision cannot be made if the reservoir has not been economically evaluated and PVT studies offers a good platform to economically evaluate the reservoir (Fattah and Lashin, 2018). According to Standing, (1947) the PVT analysis helps in properly guiding the planning and installation of the production and transportation facilities for any producing reservoir. (Standing, 1947).

PVT studies also acquaint us with the volume of gas that is dissolved in the crude and API gravity of crude oil so that gas facilities and pipelines can be designed for that reservoir. This is because every reservoir is unique, so the uniqueness of each reservoir must be established by using the PVT analysis. PVT studies are highly desirable to properly evaluate crude oil reservoirs (Udegbunam and Owolabi, 1983).

II. MATERIALS AND METHOD

a) Materials

Most of the experiments and measurements in this chapter are carried out using RUSKA instruments (Note: RUSKA is an American Engineering firm that manufactures high precision instrument for measuring reservoir fluid properties). RUSKA research precision The RUSKA dead weight gauge or the Heise gauge is used to measure pressure. RUSKA gasometer is used to measure gas volume, RUSKA visual liquid phase PVT cell is used to carry out PVT experiment, pod distillation column is used for low temperature distillation of the reservoir fluid, temperature (Jones and Roselle, 1978). Other equipment and accessories used in the analysis are viscometer, barometer, mercury pumps, gas chromatograph, and low- and high-pressure gauges. The key material for analysis is a "sample" of reservoir fluid, and the different sampling techniques of the reservoir fluid are discussed below. (Fattah and Lashin, A. 2018).

b) Method

• Sampling of Reservoir Fluid

There are basically two ways of collecting oil sample from a reservoir.

- i. Direct subsurface sampling, and
- ii. Surface separator sampling, followed by recombination of oil and gas phases to produce the desired gas/oil ratio. Whichever, technique is used, the same basic problem exist; that is, to ensure that the ratio of gas-to-oil in the composite sample is the same as that existing in the reservoir.

Conditioning a well is a prerequisite in obtaining a representative fluid sample from the well. Well conditioning is the process whereby the well is produced for a sufficient length of time by flowing the well through test separator for about 24 hours or more to bring about stable condition, with an opening (choke size) small enough not to cause appreciable pressure drop in the vicinity of the well bore but large enough to clean out mud filtrate and liquid accumulation in the tubing (Mahdiani and Kooti, 2016). Well conditioning is most critical when the reservoir fluid is saturated (that is, the oil and gas phase co-exist is the reservoir pressure and temperature). A reduction in pressure around the well bore, which occurs as the well is being produced, alters the composition of the fluid before it enters the well bore; the objective of well conditioning is to remove this altered fluid in and around the well bore, by replacing it with a representative or unaltered fluid from the formation.

The following general facts should be noted when obtaining a representative reservoir fluid sample for laboratory studies:

1. There is no assurance that any sample obtained from one well is representative of the fluid throughout the reservoir.

- 2. There composition of the fluid can vary due to gravity segregation in thick pay zones or due to movement of fluid from different formations (fractures, faults) to form the same reservoir with the same structural elevation over geologic times.
- Sufficient number of samples should be taken from different wells soon after discovery of the reservoir. This will define the average fluid properties of the reservoir.
- 4. Complete analysis of all the samples taken may not be necessary.

• Subsurface or Bottom Hole Sampling

Since there is pressure drop as a result of flowing a well for a considerable period of time (24 hours or more) during well conditioning, it is necessary to shut in the well after conditioning for pressure to build up to the reservoir pressure before taking sample. In most cases, bottom hole sampling is always associated with pressure measurements in the well to estimate the bubble point at various depths, often prior to sampling. If the well has been shut in for a long time and the pressure at the lowest oil level in the well is above estimated bubble point pressure, the well should be flowed at a "bleed" rate to introduce fresh reservoir fluid into the well bore. If the pressure is close to the bubble point pressure, the well should be shut in for sampling. If the estimated bubble-point pressure at the lowest oil level is above the existing pressure at that point, the use of another well must be considered because sample taken from such well will not be representative of the reservoir fluid (Kanu and Ikiensikimama, 2014). If sample taken from such well will not be representative of the reservoir fluid. If the well is making any water-cut during production, the well should be shut in and tested for water.

The best place to obtain the sample is the lowest point in the well bore with uniform pressure gradient. To identify this point, a pressure gradient is run just prior to sampling. The oil pressure gauge is lowered to perforation, if possible, to record present bottom hole pressure and temperature. These pressures are translated to pressure gradients and the gradients plotted as a function of depth. Oil gradients vary from 0.2 psilft to 0.38 psi/ft for high gas content to low gas content crude respectively (Mahdiani and Kooti, 2016). The water level is located by plotting pressure gradient against depth. The oil-water contact is at the depth where the gradient changes from one representative of the oil to that of water (water gradient is about 0.4 psi/fl or greater). The sampling point should be picked at about 50 feet above the oil-water contact point if this point is well defined on the plot. If the contact point is not well defined, the sampling point should be picked from the lowest oil level with a defined pressure reading. The sampler shown in Appendix B (Fig. B 1) is prepared and run into the hole (borehole) on wire line to the reservoir depth as shown in Fig. B2, and a sample of the reservoir fluid is collected from the subsurface well stream at the prevailing bottom hole pressure (Mahdiani and Kooti, 2016). Details of the preparation of the sampler and sampling procedure are given below (Reservoir Fluids Laboratory Nigeria Limited).



Figure 1: Diagram showing a bottom hole sampler (Mahdiani and Kooti, 2016)

• The Advanced System for all your Subsurface Sampling Applications

The single-phase reservoir sampler (SRS) is a specialized system that maintains the sample in a single-phase condition above reservoir pressure as the tool is retrieved from the hole. This reliable technology provides truly representative samples—which is essential for measurements requiring samples in unaltered conditions, such as pressurized pH measurements in formation water or asphaltene deposition analysis in oil.

Regardless of your sampling application, the SRS enables controlled, uncontaminated reservoir sampling without sample flashing. The unaltered sample is retrieved at the surface in its single-phase state, requiring no recombination before transfer. Eliminating sample recombination at the surface means your sample transfer takes only minutes instead of hours. The mercury-free, pressure-compensating SRS can be run in strings of up to eight tools on slickline, wireline, or electric line, coiled tubing, or sucker pump rods (Hashemi et al., 2020). Each SRS has its clock, giving you complete flexibility in deciding when and at what depth it takes a sample.

- Summary of Bottom Hole Sampling
- i. Check the operation of the sampler and tools before leaving for the field.
- ii. Pressure gradient should be run before sampling.
- iii. Preferably, the well should be shut in while sampling.
- iv. When sampling with a clock system, leave the sampler in the hole for at least 10 minutes past the set time.
- v. Make sure two samples from the same point have the same bubble point pressure.
- vi. Shear-pin method should only be used if there is an uncorrectable failure of clock systems in the field.
- Surface Sampling

Here, separator oil and gas samples are taken separately. The method employed in sampling separator oil is the method of displacement, where the separator oil displaces a mixture of glycol and water in a cylinder (Hashemi et al., 2020). The objective of this method is to obtain a sample of the separator oil with no loss of dissolved gas or contaminating gas. The general procedure for obtaining separator oil and gas samples is as follows:

- i. Connect sampling lines (tubing) from the separator gas outlet to a gas cylinder and from the oil outlet to an oil cylinder (the gas cylinder is prepared by vacuuming, while the oil cylinder is prepared by filling the cylinder with a mixture of glycol and water).
- ii. Open the separator outlet valve to fill the sampling lines.
- iii. Check for leakages

- iv. Open the cylinder inlet valve for filling
- v. Then shut and isolate the cylinder after filling
- vi. Disconnect the cylinders and lines from the separator
- vii. Label the cylinders appropriately.
- c) Quality Check

All black oil samples arriving in the laboratory from the field after sampling are kept in a single phase by compressing them to at least 2000psi above reservoir pressure and subjected to quality check before deciding on which sample or set of samples to use for analysis.

• Subsurface Samples

All subsurface samples are heated to the temperature condition in the reservoir, and bubble- point pressure is determined in the laboratory and compared to field bubble-point pressure. A portion of the sample is also "flashed" and the liberated gas is run through gas chromatograph to determine any air contamination (Hashemi et al., 2020). (Note: flash in this context means the process of passing a portion of the oil from a condition of higher pressure and temperature to a condition of lower pressure and temperature so as to liberate gas from solution). The sample with the least or no contamination and a representative bubble-point pressure is picked for the study. For bottom hole gas samples, flashing and contamination checks are made to determine the most representative sample.

• Surface Sample

Surface samples consist of separator gas and oil. In the case of separator gas, the sample bottles are put into an oven at separator temperature for at least two hours. The opening pressure of each cylinder is checked against the separator pressure and the gas is characterised by passing it through gas chromatograph to obtain its composition up to C7+ (heptene plus), and to determine any air contamination. The sample with the least contamination and a pressure equal to the separator pressure is picked for study.

For the separator oil, a portion of the oil sample is transferred to a PVT cell at separator temperature, and the bubble-point pressure is determined (later explained in detail). A portion of the separator oil is later flashed from separator condition to atmospheric condition to determine shrinkage, and the gas from the flash is analysed to obtain the level of air contamination (Foster and Beaumont, 1987).

 Summary of Quality Check on Subsurface and Surface Oil Sample

Bottom hole samples are brought to the laboratory and their bubble-point determined at either room or reservoir temperature. The values are compared with the field data and the most representative sample is chosen. The composition of the
sample is determined by low temperature distillation (Foster and Beaumont, 1987).

Surface separator samples are brought to the laboratory after sampling from the field; the separator gas composition is analysed by gas chromatograph. The bubble-point pressures of the duplicate or triplicate samples are determined for the separator oil. These values are compared with the field data of the samples and the most representative sample is chosen and is composition is determined by low temperature distillation. (Udegbunam and Owolabi, 1983).

d) Recombination Calculation

Separator oil and gas samples from the field after passing through the quality-control test in the laboratory have to be recombined to the initial producing gas/oil ratio as follows (Moses, 1986).

$$G_{CC} = \frac{G}{5.61458}$$
 3.1

Actual pump volume of oil required = $\frac{0.99928VK'}{G_{cc}S}$

Where

- S = Oil shrinkage factor
- V = Volume of gas in the cell, cm³
- G = Producing gas/oil ratio, SC F/STB
- G_{cc} = Producing gas/oil ratio, cm³/cm³
- K' = Gas expansion factor

III. LABORATORY EXPERIMENT

a) Constant Mass or Constant Composition Expansion This experiment is carried out at the reservoir temperature using sample 2 and the results obtained are shown in table 1.

Pressure (psig)	Relative volume (V/V _{sat})	$\frac{P_{sat} - P}{P((V/V_{sat}) - 1)}$	Liquid Phase Viscosity (cp)
4500	0.9730		0.5400
4000	0.9794		0.5200
3500	0.9851		0.5000
3000	0.9916		0.4800
2575	0.9964		0.4630
2435	1.0000		0.4600
2000	1.0820	2.6530	0.5000
1600	1.2174	2.4000	0.5600
1200	1.4796	2.1460	0.6300
800	2.0796	1.8930	0.7500
400	4.1021	1.6400	0.9200
100	17.1034	1.4500	1.2500
15	-	-	1.3800

Source: Reservoir Fluid Laboratory Port Harcourt

b) Constant Composition Expansion (CCE)

The CCE experiment also is called the Constant Mass Expansion (CME) or simply a pressure volume (PV) test is performed on black oil.

The CCE experiment is used to determine bubble-point pressure, undersaturated oil density, isothermal oil compressibility, and two-phase volumetric behaviour at pressure below the bubble-point pressure at reservoir temperature. A RUSKA visual PVT cell is filled with a known mass of reservoir fluid. The sample is initially brought (compressed) to a condition somewhat above initial reservoir pressure ensuring that the fluid is single-phase. The pressure is then decreased in steps by reducing the mercury level in the cell to attain equilibrium and the corresponding volume of the oil at each step is recorded after sufficient agitation as shown in fig. C2 showing the various steps of the CCE experiment (Foster and Beaumont, 1987). To prevent the phenomenon of super saturation or meta-stable equilibrium where a moisture remains as a single phase even though it is below the bubble-point obtained from the guality check (Standing, 1947). The actual bubblepoint pressure is obtained by plotting the recorded cell volume against the corresponding pressure, and the point of intersection of the P-V trends in the single and two-phase regions gives the bubble point pressure and volume as shown in Fig. C3. However, in the visual PVT (with a glass window), the bubble-point cell (corresponding to the first bubble of gas that evolves) could actually be observed.



Pressure

Figure B3: Determination of Bubble point CCE experiment (Foster and Beaumont, 1987)

Table 3: Separator test data of the reservoir fluid at 106°F

Pressure PSIG	Separator gas/oil ratio SCF/STB	Stock tank oil/gas ratio SCF/STB	Total gas/oil ratio SCF/STB	Formation volume factor Bosp	Stock tank oil O _{API}	Separator gas gravity γ _g sp	Stock tank gas gravity
400	551	232	783	1.456	30	0.698	1.306

Table 4: PVT data for the separator flash analysis at flash conditions

P(PSTg)	TR (OF)	RS	γ₀API	B₀F₅	γg
400	106	783			0.698
200	75	759	30	1.456	0.744
0	75	919			0.808

IV. Results and Discussion

Analysis of Results/Discussion

a) Corrected Parameters from PVT Report

The following equations are used to validate the correct PVT parameters from a PVT report:

$$R_{s}F = \frac{R_{SF_{b}}}{R_{s}db} \times R_{s}d$$

$$B_{O}F = \frac{R_{OF_{B}}}{B_{O}db} \times R_{O}d$$

Where

- $R_{s}F$ = Solution gas/oil ratio at flash conditions
- $R_{s}Fb =$ Solution gas/oil ratio at flash bubble point
- $R_{S}db$ = Solution gas/oil ratio at differential condition
- B_0F = Oil formation volume factor at flash condition
- B_0Fb = Oil formation volume factor at different bubble point
- $B_{s}d$ = Oil formation factor at differential condition
- P_b = 2000Psi, R_sFb = 783 SCF/STB, R_sdb = 83/SCF/STB
- $R_sd = 687SCF/STB$

at $P \leq P_b$

at 2000Psi

$$R_{\rm s}F = \frac{783}{831} \times 687$$

at 16000Psi

$$R_s F = \frac{783}{831} \times 561$$

 $R_s F = \frac{783}{831} \times 442$

= 416.5 SCF/STB

at P = 800Psi

$$R_{s}F = \frac{783}{831} \times 331$$

= 311.9 SCF/STB

at P = 400Psi

$$R_{s}F = \frac{783}{831} \times 214$$
$$= 201.6 \text{ SCF/STB}$$
$$\text{at P} = 15\text{Psi}$$
$$R_{s}F = \frac{783}{831} \times 0$$

= 0

From P > P_b the solution gas/oil ratio at flash condition is constant. $B_{\rm o}F~=$ Oil formation volume factor at flash condition

$$B_{o}F = \frac{B_{O}Fb}{B_{O}db} \times B_{Od}$$

 $B_0Fb = 1.456 \text{ Res BBL/STB}$

 $B_o db = 1.460 \text{ Res BBL/STB}$

$$B_{o}d = 1.460$$

For $P \leq P_b$

P = 2000Psi

$$B_{o}F = \frac{1.456}{1.460} \times 1.460$$

= 1.456 Res BBL/STB
P = 1600Psi
$$B_{o}F = \frac{1.456}{1.460} \times 1.399$$

= 1.395 Res BBL/STB
P = 1200Psi
$$B_{o}F = \frac{1.456}{1.460} \times 1.340$$

= 1.336 Res BBL/STB
P = 800Psi
$$B_{o}F = \frac{1.456}{1.460} \times 1.278$$

= 1.224 Res BBL/STB
P = 15Psi
$$B_{o}F = \frac{1.456}{1.460} \times 1.062$$

= 1.059 Res BBL/STB
$$P = 4500 \text{ Psi}$$

$$B_{o}F = \frac{1.456}{1.460} \times 1.482$$

= 1.478 Res BBL/STB
$$P = 4000 \text{ Psi}$$

$$B_{o}F = \frac{1.456}{1.460} \times 1.491$$

$$P = 3500 \text{ Psi}$$

$$B_{o}F = \frac{1.456}{1.460} \times 1.499$$

= 1.495 Res BBL/STB

P = 3000 Psi

$$B_oF = \frac{1.456}{1.460} \times 1.509$$

= 1.505 Res BBL/STB

For P > Pb

P = 2575 Psi $B_0F = \frac{1.456}{1.460} \times 1.517$ = 1.513 Res BBL/STBP = 2420 Psi $B_0F = \frac{1.456}{1.460} \times 1.522$

= 1.518 Res BBL/STB

Table 5: Corrected solution gas/oil ratio and formation volume factors at flash condition

Pressure (psig)	Formation volume factor (B _{od})	Solution gas/oil ratio at diff. (Rsd)	Gas deviation factor (Z)	Solution Gas/Oil ratio (scf/stb) (R _{sd})	Liberated Gas/Oil ratio (scf/stb)	Specific Gravity of liberated gas (γ_{o}) Air = 1.00
4500	1.482	831.0	0	0	0	1.478
4000	1.491	831.0	0	0	0	1.487
3500	1.499	831.0	0	0	0	1.495
3000	1.509	831.0	0	0	0	1.505
2575	1.517	831.0	0	0	0	1.513
2435	1.522	831.0	0	0	0	1.518
2000	1.460	687.0	144.0	0.695	647.3	1.456
1600	1.399	561.0	270.0	0.692	528.6	1.395
1200	1.340	442.0	419.0	0.699	416.5	1.336
800	1.278	331.0	500.0	0.723	311.9	1.274
400	1.211	214.0	617.0	0.794	201.6	1.208
15	1.062	0	831.0	1.936	0	1.059

b) Validation of PVT Parameters using Standing Correlations

(i) Estimation of Bubble Point Pressure (P_b)

From standing correlations for the reservoir condition

$$R_{Sb} = 647.3 \text{ SCF/STB}, TR - 186^{\circ}F, \gamma_g = 1.306, \gamma_o API = 30^{\circ}API$$

$$P_{b} = 18 \left(\frac{R_{Sb}}{\gamma_{g}}\right)^{0.83} 10^{\gamma_{g}}$$

$y_g = 0.00091 \; TR - 0.0125 \; \gamma_o API$

$$y_g = 0.00091 (186) - 0.0125 (30)$$

$$y_g = -0.20574$$

$$P_b = 18 \left(\frac{647.3}{1.306}\right)^{0.83} \ 10^{-0.20574}$$

$$P_b = 18(495.6)^{0.83} \times 0.7383$$

$$P_b = 1934.271 \text{ psi}$$

The bubble pressure = 1934.271psi

(ii) Validation of Solution Gas/Oil Ratio at Flash Condition Solution Gas/Oil Ratio (R_{so})

$$P < P_b$$
$$P = 2000 psi$$

Modeling the Constant Composition Expansion Test of Black Oil using Pressure, Volume, and Temperature (PVT) Calculations

$$R_{SO} = \gamma_{g} \left[\frac{P}{18(10)^{-Yg}} \right]^{1.204}$$

 $\gamma_g = 1.306$, P = 2000PSI, TR = 186°F, $\gamma_o API = 30$ $\gamma_g = 0.00091TR - \gamma_o API$ $\gamma_g = 0.00091$ (180) - 0.0125 (30)

 $\gamma_g = -0.20574$

$$\therefore R_{SO} = 1.306 \left[\frac{2000}{18(10)^{-0.20574}} \right]^{1.204}$$

P = 1600 PSI

$$R_{SO} = 1.306 \left[\frac{1600}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 512.9 \text{ SCF/STB}$$
$$P = 1200 \text{ PSI}$$

$$R_{SO} = 1.306 \left[\frac{1200}{18 (10)^{-0.20574}} \right]^{1.204}$$
$$= 362.78 \text{ SCF/STB}$$
$$P = 800 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{800}{18 (10)^{-0.20574}} \right]^{1.204}$$

P = 400 PSI

$$R_{SO} = 1.306 \left[\frac{400}{18 (10)^{-0.20574}} \right]^{1.204}$$
$$= 96.64 \text{ SCF/STB}$$
$$P = 15 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{15}{18 (10)^{-0.20574}} \right]^{1.204}$$

$$= 1.85 \text{ SCF/STB}$$

$$P > P_b$$

P = 4500 PSI

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$$R_{SO} = 1.306 \left[\frac{4500}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 1781.5 \text{ SCF/STB}$$
$$P = 4000 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{4000}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 1,545.9 \text{ SCF/STB}$$
$$P = 3500 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{3500}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 1,316.3 \text{ SCF/STB}$$
$$P = 3000 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{3000}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 1,093.4 \text{ SCF/STB}$$
$$P = 2575 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{2575}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 909.7 \text{ SCF/STB}$$
$$P = 2420 \text{ PSI}$$
$$R_{SO} = 1.306 \left[\frac{3000}{18(10)^{-0.20574}} \right]^{1.204}$$
$$= 844.2 \text{ SCF/STB}$$

(iii) Validation of Oil Isothermal Compressibility (C_{\circ}) at Flash Condition

 $P < P_b$

$$C_o = \frac{(5R_{sb} + 17.2T - 1180\gamma_g + 12.61\gamma_o.API - 1433)}{p(10)^5}$$

$$RS_{ob} = 647.3 \ SCF/STB, TR = 186^{\circ}F, \gamma_g = 0.698, \gamma_o.API = 30$$

FOR P = 4500psi

$$C_o = \frac{\left[5(647.3) + 17.2\ (186) - 1180\ (0.698) + 12.61(30) - 1433\right]}{4500(10)^5}$$

$$C_o = \frac{4,557.36}{p(10^5)}$$

$$C_o = 10.12 \times 10^6 \text{ Psi}^{-1}$$

$$P = 4000 \text{ psi}$$

$$C_o = \frac{\left[5(647.3) + 17.2 (186) - 1180 (0.698) + 12.61(30) - 1433\right]}{4000 (10)^5}$$

$$C_o = 11.39 \times 10^6 \text{ Psi}^{-1}$$

$$P = 3500 \text{ psi}$$

$$C_o = \frac{\left[5(647.3) + 17.2 (186) - 1180 (0.698) + 12.61(30) - 1433\right]}{3500 (10)^5}$$

$$C_o = 13.02 \times 10^6 \text{ Psi}^{-1}$$

$$P = 3000 \text{ psi}$$

$$C_o = \frac{\left[5(647.3) + 17.2 (186) - 1180 (0.698) + 12.61(30) - 1433\right]}{3000 (10)^5}$$

$$C_o = 15.19 \times 10^6 \text{ Psi}^{-1}$$

$$P = 2575 \text{ psi}$$

$$C_o = \frac{\left[5(647.3) + 17.2 (186) - 1180 (0.698) + 12.61(30) - 1433\right]}{2575 (10)^5}$$

$$C_o = 17.7 \times 10^6 \text{ Psi}^{-1}$$

$$P = 2420 \text{ psi}$$

$$C_o = \frac{\left[5(647.3) + 17.2 (186) - 1180 (0.698) + 12.61(30) - 1433\right]}{2420 (10)^5}$$

$$C_o = 18.83 \times 10^6 \text{ Psi}^{-1}$$

$$\begin{aligned} \text{InC}_{\text{O}} &= -0.664 - 1.430 \text{ InP} - 0.395 \text{ In Pb} + 0.390 \text{ InI} + 0.455 \text{ In (R}_{\text{Sob}}) \\ &\quad + 0.262 \text{ In } (\gamma_{\text{o}}.\text{API}) \\ \text{P} &= 2000 \text{ psi}, \text{TR} = 186^{\circ}\text{F}, \gamma_{\text{o}}.\text{API} = 30 \\ \text{InC}_{\text{O}} &= -0.664 - 1.430 \text{ In } 2000 - 0.395 \text{ In } 2000 + 0.390 \text{ In } 186 + 0.455 \text{)} 647.3) \\ &\quad + 0.262 \text{ In } (30) \\ \text{InC}_{\text{O}} &= -8.66136 \\ \text{InC}_{\text{O}} &= e^{-8.66136} \\ &\quad = 17.31 \times 10^{-5} \text{ psi}^{-1} \\ &\quad \text{P} &= 1600 \text{ psi} \end{aligned}$$

 $InC_0 = -0.664 - 1.430$ In 1600 - 0.395 In 1600 + 0.390 In 186 + 0.455 (647.3)

 $FOR = P \leq P_b$

+ 0.262 In (30)

$$InC_0 = -7.7291$$

(PVT) CALCULATIONS

 $InC_0 = -8.25412$ InC₀ e^{-8.25412}

 $InC_0 = 26.02 \times 10^{-5} \text{ psi}^{-1}$

P = 1200 psi

+ 0.262 In (30)

$$InC_{O} = e^{7.7291}$$

$$InC_0 = 43-98 \times 10^{-5} Psi^{-1}$$

 $InC_0 = -0.664 - 1.430$ In 800 - 0.395 In 800 + 0.390 In 186 + 0.455 (647.3)

$$InC_{O} = -60.9813$$

 $InC_{O} = e^{-6.9813}$

$$InC_0 = 92.18 \times 10^{-5} \text{ Psi}^{-1}$$

$$P = 400 \text{ psi}$$

 $InC_0 = -0.664 - 1.430$ In 400 - 0.395 In 400 + 0.390 In 186 + 0.455 (647.3)

$$InC_{O} = -5.72414$$

 $InC_{O} = e^{-5.72414}$

$$InC_0 = 32.66 \times 10^{-4} \text{ Psi}^{-1}$$

$$P = 15 psi$$

 $InC_{\rm O}$ = -0.664 - 1.430 In 15 - 0.395 In 15 + 0.390 In 186 + 0.455 (647.3)

$$InC_0 = -0.26809$$

$$InC_{O} = e^{-0.26809}$$

$$InC_0 = 13.08 \times 10^{-4} \text{ Psi}^{-1}$$

(iv) Validation of Oil Formation Volume Factor (B_o) at Flash Conditions

FROM
$$B_O = B_{Obe^{[Co(Pb-P)]}}$$

Where

 $B_{ob} = 0.972 + 0.000147 F^{1.175}$

$$\mathbf{F} = \mathbf{R}_{\text{sob}} \left(\frac{\gamma_{\text{g}}}{\gamma_o.API} \right) + 1.25 \text{ TR}$$

Modeling the Constant Composition Expansion Test of Black Oil using Pressure, Volume, and Temperature (PVT) CALCULATIONS

$$\begin{aligned} R_{ab} &= 647.3 \frac{SCF}{STB}, \gamma_g = 0.698_{yo}, API = 30TR = 186^{\circ} F \\ F &= 647.3 \left(\frac{0.698}{30}\right) + 1.25 (186) \\ F &= 247.5605 \\ B_{ab} &= 0.972 + 0.000147 (247.5605)^{1.175} \\ B_{ab} &= 1.0675 \text{ Res. BBL/STB} \\ P &> P_b \\ P &= 4500 \text{ psi} \\ B_{ab} &= 1.0675 \frac{BBL}{STB}, C O &= 10.12 \times 10^{-1} \text{ Psi}^{-1} \text{ Pb} &= 2000 \text{ psi} \\ B_{ab} &= 1.0675 \frac{BBL}{STB}, C O &= 10.12 \times 10^{-1} \text{ Psi}^{-1} \text{ Pb} &= 2000 \text{ psi} \\ B_{ab} &= 1.0675 \frac{BBL}{STB}, C O &= 10.12 \times 10^{-1} \text{ Psi}^{-1} \text{ Pb} &= 2000 \text{ psi} \\ B_{ab} &= 1.0675 \frac{BBL}{STB}, C O &= 10.12 \times 10^{-1} \text{ Psi}^{-1} \text{ Pb} &= 2000 \text{ psi} \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 4500) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 4000) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 4000) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 3000) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 3000) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675 \frac{c}{e^{10.12 \times 10^{-6}}} (2000 - 2575) \\ B_{ab} &= 1.0675$$

P = 1600 Psi $R_{so} = \gamma$ $\left(\frac{0.698}{30}\right)$ F = 512.9+1.25(186) F = 244.433 $B_0 = 0.972 + 0.000147 (244.433)^{1.175}$ $B_0 = 1.0661 BBL/STB$ P = 1200 Psi $R_{so} = 362.78 \text{ SCF/STB}$ $F = 362.78 \left(\frac{0.698}{30}\right) + 1.25(186)$ F = 240.9406 $B_o = 0.972 + 0.000147 \; F^{1.175}$ $B_o = 1.0645 BBL/STB$ P = 800 Psi $R_{so} = 222.65 \text{ SCF/STB}$ $F = 222.65 \left(\frac{0.698}{30}\right) + 1.25(186)$ F = 237.6803 $B_0 = 0.972 + 0.000147 (237.6803)^{1.175}$ $B_0 = 1.0630 BBL/STB$ P = 400 Psi $R_{so} = 96.64 \text{ SCF/STB}$ $F = 96.64 \left(\frac{0.698}{30} \right) + 1.25(186)$ F = 234.748 $B_o = 0.972 + 0.000147 \ (234.748)^{1.175}$ $B_o = 1.0617 BBL/STB$ P = 15 Psi $R_{so} = 1.85 \text{ SCF/STB}$ $F = 1.85 \left(\frac{0.698}{30}\right) + 1.25(186)$ F = 232.543 $B_o = 0.972 + 0.000147 \ (232.543)^{1.175}$

(v) Validation of Oil Viscosity (μ_{o}) at Flash Conditions

For $P > P_b$

$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

 $M = 2.6P^{1.187} e^{[-11.513 - 8.98(10^{-5})P]}$

 $M = 2.6(4500)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 4500]}$

 $M = 2.6(4500)^{1.187} e^{-11.9171}$

M = 0.3765

For P = 4500 psi

From $\log_{10}[\log_{10}(\mu_{obd} + 1) = 1.8653 - 0.025086(\gamma_o.API) - 0.5644\log TR$

 $\log_{10}[\log_{10}(\mu_{od} + 1) = 1.8653 - 0.025086(30) - 0.5644\log(186)]$

=-0.16819

$$\log_{10}(\mu_{od} + 1) = \log_{10}^{-1} - 0.16819$$
$$\log_{10}(\mu_{od} + 1) = 0.67890$$
$$\mu_{od} + 1 = \log_{10}^{-10.67890}$$
$$\mu_{od} + 1 = 4.7743$$
$$\mu_{od} = 4.7743 - 1$$
$$\mu_{od} = 3.7743CP$$

From $\mu_{ob} = A \mu_{ob}^{B}$

$A = 10.715 (R_{so} + 100)^{-0.515}$
$B = 5.44 \left(R_{so} + 150 \right)^{-0.338}$
At $P = 4500 psi$, $R_{so} = 1781.5 SCF / STB$
A = 0.22061
B = 0.42166
$\mu_{ob} = A \ \mu_{ob}^{ B}$

 $A = 0.2206, B = 0.42166, \mu_{obd} = 3.7742 CP$

 $\mu_{ob} = 0.2206 (3.77420)^{0.42166}$ $\mu_{ob} = 0.3862 CP$ $\mu_{ob} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$ $\mu_{ob} = 0.3862, P = 4500 \text{ psi}, P_b = 2000 \text{ psi}, M = 0.3765$ $\mu_{ob} = 0.3862 \left(\frac{4500}{2000}\right)^{0.3765}$ $\mu_{ob} = 0.524 CP$ $M = 2.6P^{1.187} e^{[-11.513 - 8.98(10^{-5})P]}$ $M = 2.6 (4000)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 4000]}$ $M = 2.6(4000)^{1.187} e^{-11.8722}$ M = 0.3424 $\log_{10}[\log_{10}(\mu_{od} + 1) = 1.8653 - 0.025086(30) - 0.5644\log(186)$ =-0.16819 $\log_{10}(\mu_{od} + 1) = \log_{10}^{-1} - 0.16819$

From $\mu_{ab} = A \mu_{ab}^{B}$

For $P = 4000 \, psi$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

 $\log_{10}(\mu_{od} + 1) = 0.67890$

 $\mu_{od} + 1 = \log_{10}^{-10.67890}$

 μ_{od} +1 = 4.7743

 $\mu_{od} = 4.7724 - 1$

 $\mu_{od} = 3.7742 CP$

For $P = 4000 \, psi, R_{so} = 1545.9 \, SCF / STB$

 $A = 10.715(1545.9 + 100)^{-0.515}$

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A = 0.4406
$B = 5.44 (1545.9 + 150)^{-0.338}$
B = 0.4406
$\mu_{ob}=A \; \mu_{ob}{}^B$
$\mu_{od} = 0.2363(3.7742)^{0.4406}$
$\mu_{od} = 0.4242 CP$
$\mu_o = \mu_{ob} iggl(rac{P}{P_b} iggr)^M$
$\mu_{ob} = 0.4723 \left(\frac{4000}{2000}\right)^{0.3424}$
$\mu_{ob} = 0.5378 CP$
$M = 2.6 P^{1.187} e^{[-11.513 - 8.98(10^{-5})P]}$
$M = 2.6(3500)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 3500]}$
$M = 2.6(3500)^{1.185} e^{-11.8273}$
M = 0.3057

From $\mu_{ob} = A \mu_{ob}^{B}$

For $P = 3500 \, psi$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

 $\mu_{ob} = 3.7742 \, CP$

For $P = 3500 \, psi, R_{so} = 1316.3 \, SCF \, / \, STB$

$$A = 10.715 (1316.3 + 100)^{-0.515}$$
$$A = 0.2554$$
$$B = 5.44 (1316.3 + 150)^{-0.338}$$
$$B = 0.4628$$

 $\mu_{ob} = A \,\mu_{ob}^{B}$

 $A = 0.2554, B = 0.4628, \mu_{ob} = 3.7742CP$

$$\mu_{od} = 0.2554 (3.7742)^{0.4628}$$
$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$
$$\mu_{ob} = 0.4723 \left(\frac{3500}{2000}\right)^{0.3057}$$
$$\mu_{ob} = 0.5604 \, CP$$

For $P = 3000 \, psi$

 $M = 2.6(3000)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 3000]}$

$$M = 0.2662$$
$$\mu_{obd} = 3.7742 CP$$
$$\mu_{ob} = A \ \mu_{ob}^{B}$$
$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

For $P = 3000 \ psi$, $R_{so} = 1093.4 \ SCF \ / \ STB$

$$A = 10.715(1093.4 + 100)^{-0.515}$$

$$A = 0.2789$$

$$B = 5.44(1093.4 + 150)^{-0.338}$$

$$B = 0.4894$$

$$\mu_{od} = 0.2789(3.7742)^{0.4894}$$

$$\mu_{od} = 0.5342 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.5342 \left(\frac{3000}{2000}\right)^{0.2662}$$

$$\mu_{ob} = 0.5951 CP$$

$$P = 2575 psi$$

 $M = 2.6(2575)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 2575]}$ $M = 2.6(2575)^{1.187} e^{-11.744235}$ M = 0.23073 $\mu_{obd} = 3.7742 CP$ $\mu_{ob} = A \, \mu_{ob}^{B}$ $A = 10.715 (R_{so} + ^{-0.515})$ $B = 5.44 (R_{so} + 150)^{-0.338}$ For $P = 2575 \, psi, R_{so} = 909.7 \, SCF / STB$ $A = 10.715(909.7 + 100)^{-0.515}$ A = 0.30397 $B = 5.44(909.7 + 150)^{-0.338}$ B = 0.51652 $\mu_{ob} = A \,\mu_{ob}^{B}$ $\mu_{od} = 0.30397 \ (3.7742)^{0.51652}$

 $\mu_{od} = 0.60363$

$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

 $\mu_{ob} = 0.60363 \left(\frac{2575}{2000}\right)^6$

 $\mu_{ob} = 0.6399 CP$

At P=2420 psi

 $M = 2.6(2420^{1.18})_{e^{[-11.513-8.98(10^{-5})\times 2575]}}$ $M = 2.6(2420^{1.18})_{a^{-11.730316}}$ M = 0.21735

> $\mu_{ob} = 3.7742 CP$ $A = 10.715 (R_{so} + 100)^{-0.515}$

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$$B = 5.44 \left(R_{so} + 150 \right)^{-0.338}$$

For $P = 2420 \, psi, R_{so} = 844.2 \, SCF / STB$

$$A = 10.715(844.2+100)^{-0.515}$$

$$A = 0.31465$$

$$B = 5.44(844.2+150)^{-0.338}$$

$$B = 0.52778$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$\mu_{od} = 0.31465(3.7742)^{0.4894}$$

$$\mu_{od} = 0634256 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.634256 \left(\frac{2420}{2000}\right)^{0.21735}$$

$$\mu_{ob} = 0.66109 CP$$

$$P = 2000 psi$$

$$M = 2.6(2000^{1.18})_{e^{-11.513-8.98(10^{-5})\times2575}}$$

$$M = 2.6(2000^{1.18})_{e^{-11.730316}}$$

$$M = 0.180$$

$$\mu_{obd} = 3.7743 CP$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$A = 10.715(R_{so} + 100)^{-0.515}$$

$$B = 5.44(R_{so} + 150)^{-0.338}$$

$$At P = 2000 psi, R_{so} = 671.03SCF / STB$$

$$A = 10.715(671.03+100)^{-0.515}$$

$$A = 0.34926$$

 $B = 5.44 \ (671.03 + 150)^{-0.338}$

$$B = 0.56305$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$\mu_{od} = 0.3492 (3.7743)^{0.56305}$$

$$\mu_{od} = 73767 CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.73767 \left(\frac{2000}{2000}\right)^{0.180}$$

$$\mu_{ob} = 0.73767 \left(\frac{2000}{2000}\right)^{0.180}$$

$$\mu_{ob} = 0.73767 CP$$

$$P = 1600 \ psi$$

$$M = 2.6 \ P^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

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$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 2.6 \ (1600)^{1.187}_{J^{-1.151} - 808(10^{-5}) \cdot P^{-1}}$$

$$M = 10.715 \ (12.9 + 100)^{-0.515}$$

$$A = 10.715 \ (512.9 + 100)^{-0.318}$$

$$A = 0.39309$$

$$B = 5.44 \ (512.9 + 150)^{-0.338}$$

$$B = 0.60527$$

$$\mu_{ob} = A \ \mu_{ob}^{B}$$

 $\mu_{od} = 0.39309 \left(3.7743 \right)^{0.60527}$

For $P < P_b$

$$\mu_{od} = 5342 \ CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.87828 \left(\frac{1600}{2000}\right)^{0.143163}$$

$$\mu_{ob} = 0.8507 \ CP$$
For P = 1200 psi

$$M = 2.6 (1200)^{1.187} d^{-11.513-8.98(10^{-5}) \times 12001}$$

$$M = 2.6 (1200)^{1.187} d^{-11.513-8.98(10^{-5}) \times 12001}$$

$$M = 2.6 (1200)^{1.187} d^{-11.517} d^{-$$

For P=1200 psi

B = 0.66015

$$\mu_{ob} = A \, \mu_{ob}^{B}$$

$$\mu_{od} = 0.45428 (3.7743)^{0.66015}$$

$$\mu_{od} = 1.092 \ CP$$

$$\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$$

$$\mu_{ob} = 0.5342 \left(\frac{1200}{2000}\right)^{0.10547}$$

 $\mu_{ob} = 1.0347 \, CP$

For P = 800 psi

 $M = 2.6(800)^{1.187} e^{[-11.513 - 8.98(10^{-5}) \times 800]}$ $M = 2.6 (800)^{1.187_{e^{-11.62076}}}$ M = 0.06756 $\mu_{obd}=3.7743\,CP$ $\mu_{ob} = A \mu_{ob}^{B}$ $A = 10.715 (R_{so} + 100)^{-0.515}$ $B = 5.44 \left(R_{so} + 150 \right)^{-0.338}$ For $P = 800 \, psi, R_{so} = 222.65 SCF / STB$ $A = 10.715 \left(222.65 + 100 \right)^{-0.515}$ A = 0.5470 $B = 5.44 \ (222.65 + 150)^{-0.338}$ B = 0.73539 $\mu_{ob} = A \, \mu_{ob}^{B}$ $\mu_{od} = 0.5470 \left(3.7743 \right)^{0.73539}$ $\mu_{od} = 1.45274 \ CP$ $\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$ $\mu_{ob} = 0.5342 \left(\frac{800}{2000}\right)^{0.10547}$ $\mu_{ab} = 1.36554 \, CP$

For P = 400 psi

$$M = 2.6(400)^{1.187} e^{[-11.513-8.98(10^{-5})\times 400]}$$
$$M = 2.6(400)^{1.187} e^{-11.54892}$$
$$M = 0.03076$$

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$$\mu_{obd} = 3.7743 CP$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$A = 10.715 (R_{so} + 100)^{-0.515}$$

$$B = 5.44 (R_{so} + 150)^{-0.338}$$

$$At P = 400 \ psi, R_{so} = 96.64 SCF / STB$$

$$A = 0.93053 A = 10.715 (96.64 + 100)^{-0.515}$$

$$A = 0.7059$$

$$B = 5.44 (96.64 + 150)^{-0.338}$$

$$B = 0.84544$$

$$\mu_{ob} = A \mu_{ob}^{B}$$

$$\mu_{od} = 0.5470 (3.7743)^{0.84544}$$

$$\mu_{od} = 2.1698 \ CP$$

$$\mu_{o} = \mu_{ob} \left(\frac{P}{P_{b}}\right)^{M}$$

$$\mu_{ob} = 0.5342 \left(\frac{400}{2000}\right)^{0.03076}$$

$$\mu_{ob} = 2.06499 \ CP$$

$$\mu_{o} = 2.0645 \ CP$$

$$M = 2.6 (15)^{1.187} e^{I-11.513-8.98(10^{-5}) \times 151}$$

A

For P=15 psi

$$M = 2.6(800)^{1.187_{e^{-11.501247}}}$$
$$M = 0.6.5467 \times 10^{-4}$$
$$\mu_{obd} = 3.7743 CP$$
$$\mu_{ob} = A \ \mu_{ob}^{B}$$
$$A = 10.715 (R_{so} + 100)^{-0.515}$$
$$B = 5.44 (R_{so} + 150)^{-0.338}$$

At P = 15 psi, $R_{so} = 1.85SCF / STB$ $A = 10.715 \left(15 + 100 \right)^{-0.515}$ $B = 5.44 (15 + 150)^{-0.338}$ B = 0.968477 $\mu_{ob} = A \, \mu_{ob}^{\ B}$ $\mu_{od} = 0.93053(3.7743)^{0.968477}$ $\mu_{od} = 3.36809 \ CP$ $\mu_o = \mu_{ob} \left(\frac{P}{P_b}\right)^M$ $\mu_{ob} = 3.36809 \left(\frac{15}{2000}\right)^{6.5467 \times 10^{-4}}$ $\mu_{ob} = 4.1309 \times 10^{-4} CP$ $\mu_o = 4.1309 \times 10^{-4} CP$

Where $\mu_{ob} = dead \ oil \ vis \cos ity, \ CP$

 $\mu_{ob} = oil vis \cos ity at bubble point pressure in CP$

 $\mu_o = oil \ vis \cos ity \ in \ CP$

3.3 Tables of Value for Complete PVT Report

Table 6: Validation of PVT parameters using standing correlations

P PSIG	R _{so} SCF/STB	B _o BBL/STB	C _o (PSt ¹)	μ _ο CP
4500	1781.5	1.041	10.12 × 10 ⁻⁶	0.524
4000	1545.9	1.041	11.39 × 10⁻ ⁶	0.5378
3500	1316.3	1.047	13.02 × 10 ⁻⁶	0.5604
3000	1093.4	1.0514	15.19 × 10⁻ ⁶	0.5951
2575	909.7	1.057	17.7 × 10 ⁻⁶	0.6399
2420	844.2	1.0591	18.83× 10 ⁻⁶	0.66109
2000	671.03	1.0675	17.31 × 10⁻ ⁶	0.73767
1600	512.9	1.0661	26.02 × 10 ⁻⁵	0.8507
1200	362.78	1.0645	43.98 × 10 ⁻⁵	1.0347
800	222.65	1.0630	92.18 × 10⁻⁵	1.36554
400	96.64	1.0617	32.66 × 10 ⁻⁵	2.065
15	1.85	1.0607	13.08 × 10 ⁻⁵	4.1309 × 10 ¹⁸

C) Validating of the PVT Parameters

(i) The Bubble point pressure P_b

The bubble point pressure P_b has average error of 4.8% plotted for about 105 data point with the following ranges.

130 psia < Pb < 7,000 psia

$$100^{\circ}F < TR < 258^{\circ}F$$

(ii) The solution gas/oil ratio (R_{SO}) is valid

For 20 SCF/STB $< R_{Sb} < 1,425$ SCF/STB

$$16.5^{\circ} \text{ API} < \gamma_{\circ} \text{API} < 63.8^{\circ} \text{API}$$

$$0.59 < \gamma_g < 0.95$$

The solution $\frac{gas}{ail}$ ratio (R_{SO}) is valid with average error of 2.3%.

(iii) The oil formation volume factor B_0 is valid for the range of 1.024 < B < 2.05 RB/STB

The oil formation volume factor (B_0) had average error of 26.9%

- (iv) The oil compressibility value jumps discontinuously from 18.83 $\times 10^{-6}_{psi^{-1}}$ above the bubble to 26.02 $\times 10^{-6}_{psi^{-1}}$ just below bubble point pressure, because oil is usually much more compressible below the bubble point.
- (v) The oil viscosity μ_0 had an average absolute error for the standing correlation is 7.54% in the range

126psig < P < 9,500psig

$$0.117 \text{ cp} < \gamma_g < 1.351$$

The oil viscosity jumps from 0.737cp at P_b to 4.1309 × 10¹⁸ cp at pressure of 15sig because the oil viscosity is sensitive to pressure charges.

V. DISCUSSION OF RESULT

Crude oil usually contains some dissolved gas when in the reservoir under pressure. As the oil well are drilled and completed and oil begin to flow a time will reach that the gas dissolved in solution in the crude begin to bubble out to form two phase region the pressure at that put is called the bubble point (p_b) . From the PVT report the P_{b} usually determine during PVT analysis, the point where the solution gas/oil changes in the analyses. PVT samples most be a representative of the reservoir fluid originally in situ. The PVT report gives a bubble point pressure of 2000 psig while the standing correlation gives a P_b of 1937.371 psi, a difference of 65.7 psi error (Elkatatny and Mahmoud, 2018). The difference is due to the representation of PVT sample. The expansion of the reservoir fluids is a function of the fluid pressure in any particular part of the reservoir, calculations should be made by using different total two phase expansion factor, but to determine the average weighting them by volume to obtained reliable results. The equipment currently used by commercial laboratories in PVT analysis determines volume, with maximum error of less than 0.01% and temperature within 1%. (Tariget al., 2021)

In many flowing wells, it has been noted that the producing gas/oil ratio is a variable function of the well producing rate, if that is the case no representative sampling procedure is carried out either surface or subsurface even when the representative sample is over duplicated equal GOR can never be obtained. At below $P_{\rm b}$ the gas is increasing coming out of solutions as well the free phase expands, but oil is shrinking in volume, the formation volume factor (B_o) suppose to be unity at standard conditions of 0 psig and 60°F, above P_b the understaturated region the formation volume factor (B_o) increases as the oil compressibility (C_o) decreases until below the P_b where it decrease as the (C_o) increases (Egbogah, 1981).

Formation volume factor (B_o) relate the volume at reservoir condition to the oil volume at stock tank condition and vice versa, therefore it is written Rb/STB the oil compressibility (C_o) determine how much the oil will expand if the pressure drop by 1 psi, therefore it is in PSI⁻¹.

Above P_b , the oil compressibility is low and below P_b the oil compressibility is high. First above the $P_b, C_o = 18.83 \times 10^{-6} \ psi^{-1}$ and below P_b i.e. at 1600 psi the $C_o = 26.02 \times 10^{-5} \ psi^{-1}$ and it keep increasing to the final pressure of 15 psig where it decreased to 13.08 $\times 10^{-1}$. That means that the oil compressibility is strongly a function of the reservoir pressure (Curtis and Michael, 2000).

At above $P_{\rm b}$ the oil viscosity $\mu_{\rm o}$ increases with decrease in pressure to the bubble point pressure $(P_{\rm b})$ and below the bubble point pressure $(P_{\rm b})$ the oil viscosity $\mu_{\rm o}$ increasing drastically with decrease in pressure from 1.0347cp at 1200 psig to 4.1309 \times 10¹⁸ cp at 15 psig oil viscosity is strongly a function of reservoir pressure and reservoir temperature, the reservoir temperature is constant throughout the life of the oil well

(Arabloo et al., 2014). The viscosity of oil measures the resistance of the oil to flow, the higher the viscosity the lower the flow rate and vice visa; therefore the mobility of the oil is inversely proportional to the viscosity at constant temperature. An adjustment in the gravity of the residual oil is not required (Drohm et al., 1998).

VI. CONCLUSIONS

The pressure, volume and temperature (PVT) studies of Black oil reservoir was carried out for the purpose of determining the economic worth of a particular reservoir. This is necessary because, without the PVT studies, the reservoir engineers cannot predict or calculate or calculate or compute the probable hydrocarbon reserves available in the reservoir.

In this research work, we analyzed the black oil samples from the X Field at the Reservoir Fluids Laboratory (RFL) in Port Harcourt, Nigeria using PVT analysis. Basic PVT Parameters for the samples were derived and we validated the report by employing Standing correlations.

The test conducted during the PVT studies is Constant Composition Expansion (CCE) tests and Separator Flash (SF) test with surface and subsurface recombination sample. The analytical test shows that the crude oil is a high viscosity with an average absolute error (AAE) of 3.5% (i.e. 3.5/100 = 0.035). Gas began evolving at 2000psig and increased as the pressure decreased. Also, it was noticed that at higher pressure of 4500psig the black oil viscosity was low as 0.54 cp while at a lower pressure of 15psiag the viscosity recorded was 1.38 cp. (Tohidi-Hosseini, et al 2016).

VII. Recommendations

Based on this research work and by opinion the following recommendations can be made for the black oil PVT report analyzed in this research project.

- 1. The surface method sampling (surface recombination method) will yield more representative sample of the total fluid regardless of the presence of free gas in the flow string, because when free gas is present in the flow string at the point of subsurface sampling, a representative homogeneous immixture of total fluid will not be found, because when gas appears either static or moving column of oil the bottom home sample will usually be underestimated.
- 2. In order to check the quality of the sample, duplicate samples should always be taken if the reservoir contains a greater number of well and it is or has a high structural relief such duplicate samples should be obtained on several wells 4 to 8.
- 3. Laboratory result output samples (PVT report) must always be checked against the actual production pressure performance of the reservoir. (Drohm, et al 1988).

- 4. A reservoir simulation method should be used to regenerate the require PVT parameters for black oil, gas condensate and other reservoir before the reservoir is put into production.
- 5. This project work required the used of standing correlations to validate the basic PVT parameters of a black oil reservoir, other correlations can also be applied such as Vasquez and Beggs, Glaso or Marhran correlations can be used.

References Références Referencias

- Arabloo, M.; Amooie, M.-A.; Hemmati-Sarapardeh, A.; Ghazanfari, M.-H.; Mohammadi, A. H. Application of constrained multi-variable search methods for prediction of PVT properties of crude oil systems. Fluid Phase Equilib. 2014, 363, 121 – 130.
- 2. Cosse, R. (1993). Basics of Reservoir Engineering, Technip, Paris by Imprimerie Nouvelle.
- 3. Curtis, H.W., Michael, R.B. (2000). Phase Behaviour, Petroleum Publishing Co. Pulsa pp. 80-120.
- Drohm, J.K., Goldthorpe, W.H., and Trengove, R. (1988). On the quality of data from standard gascondensate PVT experiments, SPE Gas Technology Symposium, NS 17768, Dallas, pp. 13-68.
- Egbogah, E.O. (1981). "An improved temperature viscosity correlation for crude systems paper 83-84-32 presented at the SPE annual technical conference and Exhibition, 5-7 October, San Antonio, Texas.
- Elkatatny, S.; Mahmoud, M. (2018). "Development of new correlations for the oil formation volume factor in oil reservoirs using artificial intelligent white box technique." Petroleum 2018, 4, 178–186.
- Fattah, K. A. & Lashin, A. (2018). "Improved oil formation volume factor (Bo) correlation for volatile oil reservoirs: An integrated non-linear regression and genetic programming approach." J. Eng. Sci. King Saud Univ. 2018, 30, 398–404.
- Foster, N.F. and Beaumont, E.A. (1987). "Reservoir Evaluation, Treatise of Petroleum Geology" Geologic Basin I (Reprint Series No. 1).
- Hashemi Fath, A.; Madanifar, F.; Abbasi, M. (2020). "Implementation of multilayer perceptron (MLP) and radial basis function (RBF) neural networks to predict solution gas-oil ratio of crude oil systems." Petroleum 2020, 6, 80–91.
- Hemmati-Sarapardeh et al (2016). "A soft computing approach for the determination of crude oil viscosity: light and intermediate crude oil systems." J. Taiwan Inst. Chem. Eng. 2016, 59, 1–10.
- 11. Jones, S.C. and Roselle, W.O. (1978). Graphical techniques for determining relative permeability from displacement experiments; JPT 807. Trans AIME, 265.
- 12. Kanu, A. U., & Ikiensikimama, S. S. (2014.) "Globalization of Black Oil PVT Correlations."

Presented in SPE Nigeria Annual International Conference and Exhibition, Lagos, Nigeria, 5-7 August.

- Mahdiani, M. R.; Kooti, G. The most accurate heuristic-based algorithms for estimating the oil formation volume factor. Petroleum 2016, 2, 40–48.
- Moses, P.L. (1986). Engineering Applications of Phase Behaviour of Crude-oil and Condensate Systems, Journal of Petroleum Technology, 38(7), pp. 28-223.
- Standing, M.B. (1947). "A pressure, volume, temperature, correlation for mixtures of California oils and Gases Drilling and Production Practice" pg. 275.
- Tariq, Z.; Mahmoud & M.; Abdulraheem, (2021). "A. Machine Learning Based Improved Pressure– Volume–Temperature Correlations for Black Oil Reservoirs." J. Energy Resour. Technol. 2021, 143, 113003.
- 17. Tohidi-Hosseini, et al (2016). "Toward prediction of petroleum reservoir fluids properties: A rigorous model for estimation of solution gas-oil ratio." J. Nat. Gas Sci. Eng. 2016, 29, 506–516.
- Udegbunam, E.O. and Owolabi, O.O. (1983). Correlation for fluid physical properties of Nigerian crude, proceeding of the International SPE Conference, Port Harcourt, NS 215, Nigeria, pp. 200-205.
- Vasquez, M. and Beggs, H.D. (1987). Correlations for fluid physical property prediction. SPE Annual Technical Conference and Exhibition, NS 6719, Denver, Coloration, pp. 9-106.
- 20. Whitson, C.H. 5-7 October (1981). "Evaluating constant volume depletion Data", paper SPE 10067 presented at the SPE Annual Technical Conference and Exhibition, Son Antonio, Texas.
- Zamani, H. A. et al (2015). "Implementing ANFIS for prediction of reservoir oil solution gas-oil ratio." J. Nat. Gas Sci. Eng. 2015, 25, 325–334.

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It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing A Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. *Choosing the topic:* In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. *Think like evaluators:* If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.



6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. *Make every effort:* Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. *Know what you know:* Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. *Multitasking in research is not good:* Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. *Never copy others' work:* Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- o Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- o Simplify-detail how procedures were completed, not how they were performed on a particular day.
- o If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- o Resources and methods are not a set of information.
- o Skip all descriptive information and surroundings—save it for the argument.
- \circ $\$ Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.



Content:

- o Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- o In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- o Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- o A manuscript should complement any figures or tables, not duplicate information.
- o Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- o Recommendations for detailed papers will offer supplementary suggestions.



Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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Topics	Grades		
	A-B	C-D	E-F
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form	No specific data with ambiguous information
		Above 200 words	Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
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ISSN 9755861

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