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Raman Spectroscopic Technique to Distinguish Constituents of Hydrocarbon-Bearing Fluid Inclusions of Kerala-Konkan Basin, Western offshore, India

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Abstract

Fluid inclusion studies have a great diversity of applications in exploration geology and are necessary tools in the determination of palaeotemperature and nature of fluids associated with the rocks in a basin. Using various fluid inclusion techniques such as petrography, microthermometry and Laser Raman Spectroscopy of fluid inclusions with Hydrocarbon fluid inclusions (HCFIs) help us to understand the generation potential of the basin. The representative micron sized fluid inclusions that intruded into the different geological formations of the KK-4C-A1well drilled by Oil and Natural Gas Corporation in Kerala-Konkan Basin, India has been selected for this study. Petrographic analyses confirm the presence of HCFIs with the help of Ultraviolet (UV) light. Raman spectra of HCFIs identified in different formations were examined. The temperature of homogenization (T_h) obtained through microthermometric analysis of the fluid inclusions indicate the palaeotemperature of the sedimentary rock units. Coeval-aqueous inclusions associated to HCFIs show T_h within the oil window range 60-140°C, indicating a temperature favourable for oil generation in Kerala-Konkan Basin (K-K Basin).Characterisation of hydrocarbon bearing fluid inclusions were carried out using Raman spectroscopy. HCFIs were observed in the annealed micro-cracks of Cannanore (Early Miocene), Calicut (Early Oligocene) formation (Type I) and Kasaragod (Palaeocene to Early Eocene) Formation (Type II), might get trapped along the micro-fracture by re-healing process. Laser Raman study could decipher hydrocarbon species such as Alkanes, SO_2, COS, H_2S, *etc*.

Keywords: Hydrocarbon Fluid Inclusions, Oil Window Temperature, Raman Spectroscopy, Kerala-Konkan Basin

Introduction

Fluid inclusions can preserve palaeofluids and the prevailing conditions of fluid entrapment (Roedder, 1984; Bourdet *et al.*, 2011). Fluid inclusions are entrapped within the imperfections during the growth of a crystal (primary) or a later sealing event (secondary) (McLimans, 1987). The hydrocarbon fluid inclusions are generally trapped at the time of crystallization process or during healing of fractures within the cements (Burruss, 1981). Detailed analysis of fluid inclusion can give a thorough understanding about the diagenetic processes, thermal history and migration history of petroleum fluids (Bodnar, 1990, 2003; Goldstein, 2001; Karlsen and Skei, 2006; Shepherd *et al.,* 1985). Hydrocarbon fluid inclusions (HCFIs) offer unique insight to the conditions of accumulation of oil in petroliferous basins and are known as “hidden petroleum shows” (Lisk *et al.*, 2002). Secondary hydrocarbon fluid inclusion trails are proven as a good indicator of migration pathways of hydrocarbons and can be helpful to know the thermal history and fluid migration within the reservoir systems (Nandakumar and Jayanthi, 2016).

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Petroleum fluids are highly complex in nature and its characterisation is important for the geological interpretation and its maturity (Goldstein, 2001, 2003; Munz, 2001). In context of petroleum fluid inclusion studies, Burruss (2003a-b) put forwarded that there is a possibility to study Raman spectroscopy of petroleum inclusions and should be done under a suitable method to eliminate fluorescence interruptions (Kihle, 2012). Most common method that was employed for studying HCFIs is mainly by observing their fluorescence colour under Ultraviolet (UV) light excitation and this method is widely used for the determination of maturity, arbitrarily depending on the fluorescent colour and density (Burrus, 1981). But, the usage of visual fluorescence colour may be subjected to error, and it doesn't yield actual results and is not reliable. Hence, a quantitative non-destructive analysis for hydrocarbon bearing inclusions (HCFIs) was therefore an important matter of concern.

Fluorescence emission properties of oil inclusions are primarily due to the aromatic compounds within the hydrocarbons (Lumb, 1978), and mark the organic chemical composition. Raman spectroscopy is considered as a “non-destructive technique” which can characterize the compounds as well as solute species in fluid inclusions and it gives the chemical as well as structural characterisation of minute samples which is not feasible by usual petrography, microthermometry and other spectroscopic method like infrared-spectroscopy (Frezzotti *et al.*, 2012). It is a useful method of getting detailed composition and has been widely applied to fluid inclusions (aqueous ± gas and multiphase containing solid phase). Blocking of Raman signals due to background fluorescence is a certainty. Therefore, while attempting Raman Spectroscopy of petroleum inclusions, eliminating fluorescence interference is a must. Many previous studies have been highlighted the fluorescence inferences caused by the surrounding host mineral while studying Raman peaks of hydrocarbon fluids with short excitation wavelength (260 nm). Jayanthi *et al.* (2017) explained the conducive conditions and feasibility of 785 nm diode laser for identifying and characterizing the constituents in HCFIs samples without any fluorescence inferences. Background fluorescence can be negated by increasing the excitation wavelength of the source during Raman analysis because longer wavelength excites less fluorescence from fluorophores (Bourdet *et al.*, 2011; Frezzotti *et al.*, 2012, Jayanthi *et al.*, 2017, Jayanthi and Nandakumar, 2021; Nandakumar and Jayanthi, 2021; Thankan *et al.*, 2023).

The present study reports the characteristics of hydrocarbon fluid inclusions from a "dry" well of the Kerala-Konkan Basin (K-K Basin), a non-proven basin, Western offshore, India using Laser Raman Spectrometer (785 nm laser excitation) along with petrography and micro thermometric analysis. Probability to find the hydrocarbon in a sedimentary basin will depend upon the source rock and its maturity, type of Kerogen, organic matter present in it and the P-T conditions during different stages like diagenesis, metagenesis and catagenesis (Thankan *et al.*, 2023). Fluid inclusions especially HCFIs present in the different depths of various formations were examined and their species wise characterizations were done using a Laser Raman Micro spectrometer.

Geological Settings

Kerala–Konkan offshore Basin (K-K Basin) situated south of E-W trending Vengurla Arch and extends up to Cape Comorin in the south in the western offshore India. Westward, the K-K Basin extends to Arabian Abyssal plain and on the eastern side it is enclosed by Indian peninsular shield. The basin covers an area of around 5,80,000 km^2 from coast to 200 m isobath (National Data Repository, 2022). For this present work HCFIs from well-KK-4C-A1of K-K Basin was elected mainly from three different formations (Cannanore, Calicut and Kasaragod Formations) within the well depth ranging from 3065-5030m (Fig. 1). These three formations have major lithologies such as claystone with sandstone (Cannanore Formation/ Early Miocene), limestone with claystone and sandstone (Calicut/ Early Oligocene), and shale, sandstone, siltstone, limestone (Kasaragod Formation/ Palaeocene to Early Eocene).

Materials and Methods

Sample Details

Drilled core cutting samples of KK-4C-A-1 well (latitude 09°57'48.54"N and longitude 75° 12' 19.26" E) in the K-K Basin, Western offshore, India, were collected from the core library of Regional Laboratory (RGL) of ONGC, Government of India. Collected samples from the depth of 2750-6105 m were sieved, washed, dried (below 50°C) and soaked within an epoxy resin-hardener mixture and doped with a fluorescent-quenching dye and then made into doubly polished wafers (up to 0.3mm thickness) for fluid- inclusion non-destructive studies. In the sedimentary core cuttings of the well KK-4C-A-1 of K-K Basin, hydrocarbon fluid inclusions were observed in quartz, feldspar and calcite grains of sandstone, claystone and limestone lithology of lower depths ranging from (3065-5030 m) are mainly from three formations (Cannanore, Calicut and Kasaragod Formations). HCFIs of Cannanore (Early Miocene) and Calicut (Early Oligocene) Formations of well-KK-4C-A1 are mainly in the form of monophase blebs of bitumen like inclusions (Type I). At Kasaragod Formation (Palaeocene to Early Eocene) secondary fluid inclusions with monophase and biphase (Type II) inclusions shows good oil fluorescence towards the lower depths ranging from 3980-5030 m. Raman spectroscopic analyses were carried out in 9 hydrocarbon fluid inclusion assemblages (FIAs), each one having a minimum of 5-10 individual inclusions (depth 3065-5030 m) and its petrographic observations with lithostratigraphic details and ages are provided in the Table 1.

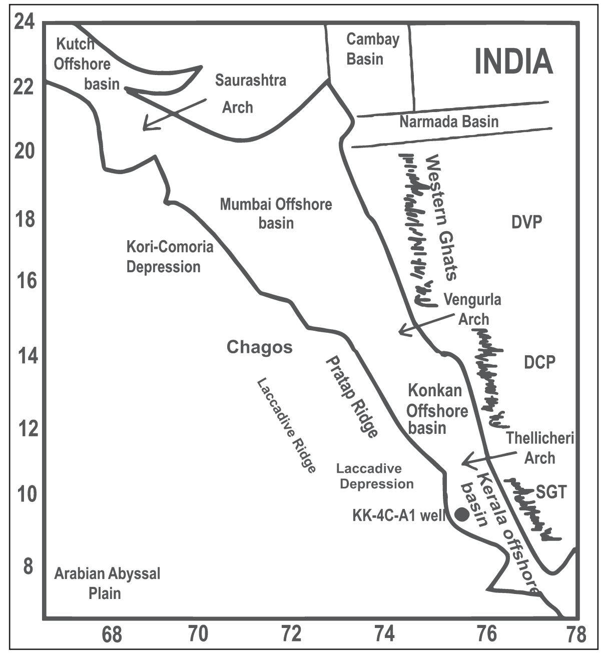

Fig.1. Location map of the study area (KK-4C-A1 well) within the Kerala Konkan Basin, Western offshore, India, (*After* Jayanthi and Nandakumar, 2021).

Study Procedure and Instrumentation

Fluid inclusion studies were subjected to petrographic analyses using Leica Microscope, LAS V3.8 and this microscope is attached to a UV light source (λ= 365 nm) for the identification of hydrocarbon bearing fluid inclusions. Microthermometric data were acquired with a Linkam MDS 600 heating-freezing stage. This stage is placed under a microscope, so that the phase changes occurring as well as the temperatures at which these changes take place can be observed. Calibrations were done with -56.6°C (triple point of CO_2). In these heating-cooling experiments the melting temperature of fluid inclusion is designated as T_m and homogenisation temperature is designated as T_h for two phase inclusions (liquid-vapour). While heating and cooling the accuracy is measured at ±0.1°C.

Table 1: Petrographical observations of HCFIs studied from the well KK-4C-A1 along with depth, age and lithology, Kerala-Konkan Basin, India.

S. No.	Depths(m)	Formation and Age	Major lithology	Petrographical observations
1	3065-3070	Cannanore Formation/ Early Miocene	Claystone with minor sandstone	Monophase secondary inclusions trapped in the healed micro-fractures of quartz grains. Size of inclusions varied between 0.1µm to 4µm. Shape of HCFIs are observed as subrounded.
2	3075-3080	Cannanore Formation/ Early Miocene	Claystone with minor sandstone	Monophase HCFIs found as secondary trails of quartz and feldspar grains. Size of inclusions varied between 0.2 µm to 3 µm, and shape of inclusions are rounded, elongated etc.
3	3080-3085	Cannanore Formation/ Early Miocene	Claystone with minor sandstone	Biphase HCFIs found as secondary fractures in quartz grains. Their size varied between 0.5 µm to 6 µm and shape of inclusions are rounded, elongated, irregular and ovoidal.
4	3090-3095	Cannanore Formation/ Early Miocene	Claystone with minor sandstone	Monophase HCFIs found as secondary fractures of quartz and feldspar grains. Size of inclusion varied between2 µm to 11 µm and shapes of inclusions are observed as rounded, elongated, irregular etc.
5	3205-3210	Calicut Formation / Early Oligocene	Limestone with claystone and minor sandstone	Monophase HCFIs are seen within the secondary fluid inclusion trails. Size of inclusions varied between1 µm to 4 µm.Shapes of inclusions are observed as elongated, and irregular.
6	3980-3985	Kasaragod Formation/ Palaeocene to Early Eocene	Shale, sandstone, siltstone, limestone	Biphase HCFIs observed in secondary trails of quartz, feldspar grains. Size varied between 1 µm 6 µm, and shape is irregular and stretched.
7	3985-3990	Kasaragod Formation/ Palaeocene to Early Eocene	Shale, sandstone, siltstone, limestone	Biphase HCFIs in micro-fractures (secondary trails) of quartz and feldspar grains. Size varied between 1 µm to 3.5 µm and shapes of inclusions are sub-rounded, elongated etc.
8	4575-4580	Kasaragod Formation/ Palaeocene to Early Eocene	Shale, sandstone, siltstone, limestone	Monophase inclusions trapped in the secondary fluid inclusion trails of quartz, feldspar, and calcite grains with size varied between1 to 5 µm with subrounded shape.
9	5025-5030	Kasaragod Formation/ Palaeocene to Early Eocene	Shale, sandstone, siltstone, limestone	Biphase HCFIs trapped in the fluid inclusion trails (secondary) of quartz, feldspar, and calcite grains with size varied between 1 to 4µm with subrounded shape.

Laser Raman spectroscopic studies were carried out for each fluid inclusion sample using a Raman Microscope attached with an in Via Reflex Raman Spectrometer which offers an automated alignment by Renishaw-WiRE 3.4 software. All equipment are housed at the National Facility for Geofluids Research and Raman Analysis, NCESS, Thiruvananthapuram, India. The fluid inclusions including HCFI(s) are observed and focused using an X50 and X100 magnification objective lens of the Raman microscope. Raman spectrometer along with the laser having 785nm wavelength is used to characterize the constituents of HCFIs of K-K Basin, India. To eliminate the background fluorescence, we used a fluorescence quencher along with resin-hardener mixer during wafer preparation along with the adequate settings for obtaining best Raman signals from the natural-HCFIs (Jayanthi *et al.*, 2017).

Results and Discussion

Fluid Inclusion Petrography

Fluid inclusions from the studied samples are either present as isolated (primary) or occur along trails (secondary and pseudo secondary). Some of the fluid inclusions due to their probable magmatic origin from the provenance have been excluded from further analysis. In KK-4C-A1, HCFIs of Cannanore and Calicut Formations are blebs of bitumen like inclusions appeared to be brownish to blackish in transmitted light within the micro-fractures of quartz and feldspar (type I) shown in Fig.2 (A-D). Biphase hydrocarbon fluid inclusions in annealed micro-cracks towards the lower depths were found largely in the diagenetic minerals of quartz (Mahantesha *et al.*, 2022), feldspar and calcite grains of sandstone, claystone and limestone lithology of Kasaragod Formation and might get trapped along the micro-fracture by re-healing process (type II) and are shown in Fig.2 (E-F). Type I and type II HCFIs can

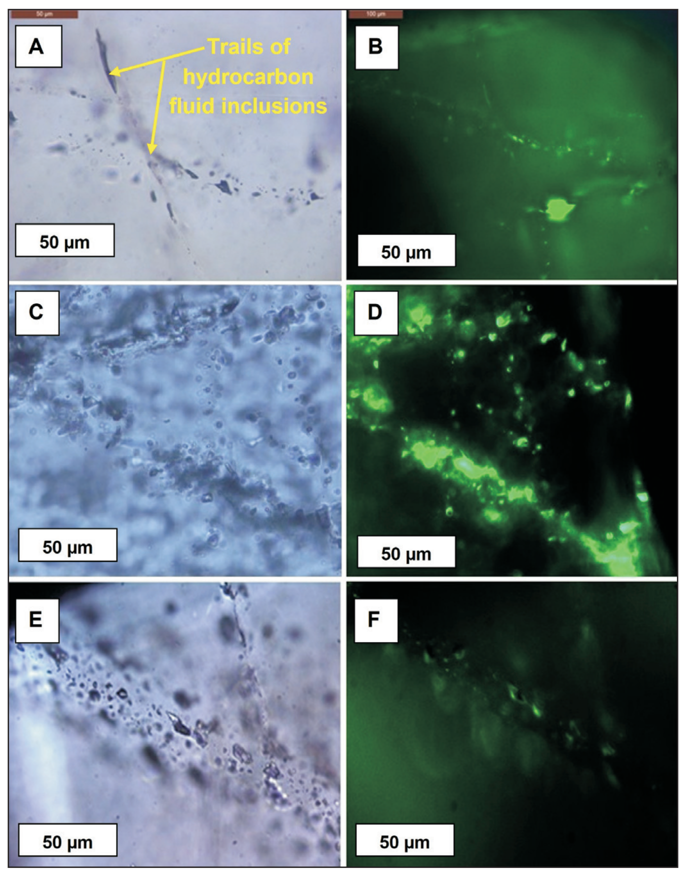

Fig.2. Type I-HCFIs trapped in the secondary fractures of quartz and feldspar grains at 3065-3070m (A-B), and 3075-3080m (C-D), respectively from Cannanore Formation. Type II-HCFIs trapped in the secondary fractures of quartz grain at 3980-3985m (E-F). (A, C and E) Bright field image of HCFIs and (B, D and F) Fluorescence images of HCFIs from Kasaragod Formation, Kerala Konkan Basin, India.

be easily recognized by their appearance in secondary trails that are often cut grain boundaries and some of them are showing migrating trend (Jayanthi and Nandakumar, 2021; Nandakumar and Jayanthi, 2021). Type I (Fig.2 A-D) hydrocarbon inclusions in secondary trails indicating less quality bitumen like inclusions. Type II (Fig.2 E-F) inclusions mainly seen in Kasaragod Formation are very less in number. HCFIs were identified along healed fractures with shapes varied from sub rounded to irregular and their size range between from 0.1 to 11µm. Majority of the HCFIs (type I and type II) within the study area are in annealed fractures and is in secondary trails indicates that oil was present during the fracture healing and post crystallization process (Fig. 2). Biphase aqueous and aqueous-carbonic inclusions (Jayanthi and Nandakumar, 2021; Nandakumar and Jayanthi, 2021) were also observed in different depths of the K-K Basin indicating heterogeneous trapping conditions.

Microthermometry

In fluid inclusion studies, non- destructive technique like microthermometric analysis provide valuable information on the temperatures at which the fluids are trapped, and the temperature experienced in the rock history and the compositions of the fluids (Goldstein and Reynolds, 1994). The purpose of this analysis is to observe and record the different phase changes of fluid inclusions at different temperatures.Coeval-aqueous inclusions in trails (individual FIAs) associated with HCFI(s) were taken for the microthermometric analyses and their homogenization temperatures were recorded. Coeval aqueous inclusions from 3065-5030 m depth show temperature of homogenisation (T_h) of 60-160°C, which falls in the Oil window range (T_h= 60-140°C).The frequency-temperature histogram of homogenization of these fluid inclusions is shown in Fig.3. In Cannanore Formation (3065-3180 m), fluid inclusions in sandstone, limestone and claystone lithologies provided a T_h, 60-153°C range. In Calicut Formation (3190-3345 m), fluid inclusions in sandstone, claystone and limestone at four different depths showed a T_h of 120-146°C. In Karwar Formation (3475-3490 m), fluid inclusions in sandstone and claystone showed a T_h of 62-82°C. In Kasaragod Formation (3880-5050 m), claystone, sandstone, siltstone and limestone showed a T_h of 94-164°C.

Temperature of homogenization (T_h) in these formations indicates that there was a conducive setting favorable for Oil generation in K-K Basin. At some depth intervals in Cannanore Formation (3130-3135m, 3140-3145 m), Calicut Formation (3215-3220 m and 3340-3345 m) and Kasaragod Formation (4575-4580 m and 5045-5050 m), rocks exhibited a T_h 140-180°C, which falls under the Gas window range. Microthermometric analysis of fluid inclusions (non-HCFIs) from the well KK-4C-A1 indicates that majority of the fluid inclusions in trans-granular trails belong to H_2O-NaCl and H_2O-NaCl-KCl systems and some isolated inclusions are identified as aqueous-carbonic. Based on the T_h and T_m (temperature of melting) of ice, density and salinity of those inclusions were calculated using AQSO and BULK programs of FLUIDS package. Salinity of both primary and secondary aqueous fluid inclusions in K-K Basin varies from a minimum of 0.7 and maximum of 18.5equivalent wt% NaCl. The H_2O-KCl inclusions with T_h between 40–80°C are showing salinity range 2-6.7 equivalent wt% NaCl. H_2O-NaCl-KCl inclusions with T_h between 85-110°C are showing salinity range between 0.7-1.39 equivalent wt% NaCl. H_2O-NaCl inclusions with T_h between 110-153°C showing salinity 2.8-9 equivalent wt% NaCl. Aqueous fluids in the well KK-4C-A1 correspond to a low density of 0.2 to 0.65 g cm^{-3}.

Primary fluid inclusions are rich in aqueous-carbonic inclusions along growth zones representing the early diagenetic phase and secondary fluid inclusions with H_2O-NaCl and H_2O-NaCl-KCl systems representing the later stage of diagenetic phase. Majority of fluid inclusions in the well-KK-4C-A1 are homogenized into liquid. Most of the coeval inclusions associated to HCFIs fall in the Oil-window temperature giving supportive evidence of favorable condition present there for the generation of hydrocarbon within the dry well (KK-4C-A-1) of K-K Basin. But, unfortunately no potential generation and accumulation is reported in the basin yet.

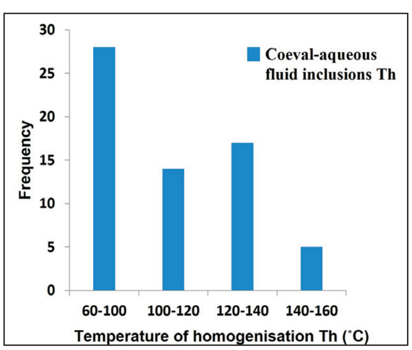

Fig.3. Histogram of homogenization temperatures of coeval-biphase aqueous fluid inclusions associated to Type I and Type II- HCFIs from the Kerala Konkan Basin, India**.**

Raman Spectroscopy

Raman Spectroscopy is a "non-destructive technique" which can characterize the solid phases, liquid, gaseous, and solute species within the fluid inclusions (Frezzotti *et al.*, 2012). Many studies stated that the fluorescence influence might be totally avoided while doing Raman spectroscopy in hydrocarbon fluid inclusion analysis (Frezzotti *et al.*, 2012). Therefore, only a smaller number of studies are reported in natural hydrocarbons using Raman technique (Orange *et al.*, 1996; Bourdet *et al.*, 2011). Orange *et al.* (1996) reported the absence of hydrocarbons in natural HCFIs, but observed it in oil samples. Background fluorescence from aromatic compounds in HCFIs and the over-lapping bands from host mineral are the possible hurdles while doing Raman analysis. Jayanthi *et al.* (2017) overcame this by wafer preparation technique done with fluorescence quenchers, proper selection of wavelength (785nm), appropriate use of laser power (1.5 mW and exposure time of 20 seconds) and optics *etc*. It helped to acquire best Raman signals from natural HCFIs from a dry well (RV-1) in Mumbai offshore Basin (proven basin), India. The method of wafer preparation and the feasibility of 785 nm diode laser bring out desirable results from natural HCFIs (biphase L+V inclusions) in RV-1 of Mumbai offshore Basin, whereas, majority of HCFIs here in K-K Basin are like blebs of translucent inclusions. But, the notch filters used in the Raman spectrometer for this study allows the very weak signals with high intensity. So, this present study also tried to overcome the background fluorescence influence from even a small quantity of HCFIs from the studied samples in all the possible ways. Generally, the major constituents of petroleum are hydrocarbons, NSO compounds and inorganic gases like CO_2, N_2, and H_2S *etc*. Major hydrocarbon species in type I and type II inclusions are identified by Raman analysis from K-K Basin giving prominent peaks corresponds to species such as Benzene, Bromobenzene, Cyclohexane, SO_2, COS, H_2S and alkanes *etc*.

Type II HCFIs (biphase) in secondary trails towards lower depths are giving prominent peaks with good intensity. Raman peaks of type II are as follows, benzene observed at 1486 cm^{-1}, bromobenzene observed at 1580 cm^{-1} and cyclohexane observed at 786 cm^{-1}. One peak at 524 cm^{-1}representssulphur dioxide (SO_2) and a peak at 857 cm^{-1} represent COS and another peak at 2580 cm^{-1}shows H_2S gas. At 854 cm^{-1} $CaCO_3$ peak is observed. A broad band at 3100-3500 cm^{-1} represents water peak. Peaks at around 1285cm^{-1}, 1387 cm^{-1} corresponding to CO_2 rich aqueous fluids are also identified from the study area (Fig.4A-C). On the other hand, large number of monophase bitumen inclusions (type I) from different depths representing less prominent Raman peaks with very low intensity as shown in (Fig.4D).These monophase dark inclusions in secondary fluid inclusion trails are mainly composed of alkanes showing peaks at 2878 cm^{-1}, 2939cm^{-1}. Methane peaks are observed at different peaks at2913 $cm^{-1}$and 3019 cm^{-1}, ethane peaks observed at 2850 cm^{-1}, 2895cm^{-1}, 2952cm^{-1},2953 cm^{-1}, and propane peaks observed at 2939 $cm^{-1}$and butane peaks observed at 2878 cm^{-1}. Compared to biphase (liquid+gas) HCFIs, monophase (gaseous) dark HCFIs inclusions in secondary fluid inclusion trails are abundant in the study area.

The API Gravity measures the lightness or heaviness of oil and other liquid hydrocarbons (Nandakumar and Jayanthi, 2016). The scale of API Gravity is inversely related to relative density of crude oils, which means lighter the crude higher the API Gravity and better the market value. Nandakumar and Jayanthi (2016, 2021) reported the relation between API gravity and fluorescence emission of oils with a laser exciting at 405 nm and derived an arithmetic equation and a scattergram for calculating unknown API Gravities with fluorescence emission technique. To determine the hydrocarbon quality of oils in terms of API gravity, fluorescence emission of oils in HCFIs in minerals were studied with a 405 nm laser (20mW) and the API gravity calculated using the previously derived arithmetic equation (1) with the emission ratio values at F620/F560 (Nandakumar and Jayanthi, 2016, 2019; Jayanthi and Nandakumar, 2021). The API gravity of KK-4C-A1 well samples from the 3495-3500m, 3270-3275m, 065-3070m and 3445-3450m were determined using the equation (1) and found as the API Gravity is ranging from 25-32 (Jayanthi and Nandakumar, 2021; Nandakumar and Jayanthi, 2021) and also indicates the presence of oil in the adjoining areas of K-K Basin (Jayanthi and Nandakumar, 2021).

(Where X is the value of fluorescence derived using the emission ratio at F620/F560 and $y_0 = 23$, $X_0 = 2.55$, and $t = 1.4$)

$$y = y_0 (X_0 - X)^t \pm 1 \qquad (1)$$

Even though KK-4C-A1 is designated as a dry well, the prediction of Oil window depth range for generation and hydrocarbon species from HCFIs of different depths are a good sign for finding hydrocarbon in nearby areas. Emergence of fluid inclusions research especially Raman spectroscopic studies of HCFIs under the specific conducive conditions have wide applications in oil exploration industry and it can act as a preliminary tool to learn about the HCFIs presence within a sedimentary basin.

Conclusions

The present study reports the constituents of hydrocarbon

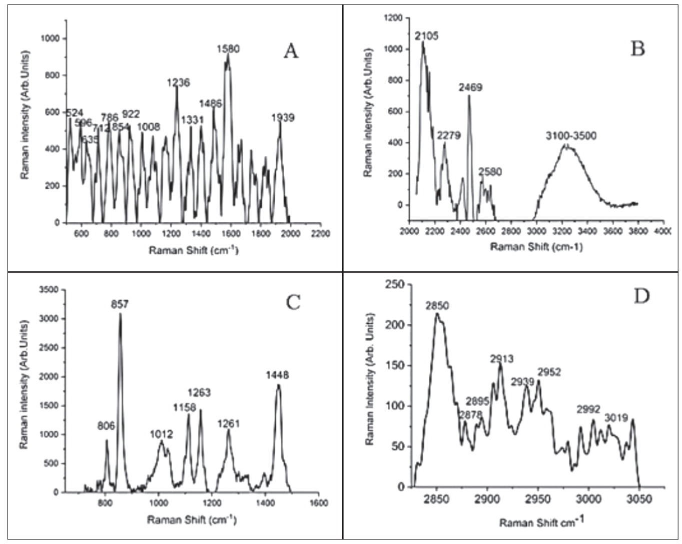

Fig.4. Raman spectrum of natural HCFIs. Type I (A, C), Type II (D) and water (C) from the well KK-4C-A1, Kerala Konkan Basin, India.

bearing fluid inclusions in a dry well that too in a non-proven K-K Basin in the form of HCFI(s). Petrographic, microthemometric and Raman Spectroscopic results showed that the well-KK-4C-A1 designated as dry have the possibility to find less quality bitumen like inclusions (majority) with an API gravity (25-32) indicating medium to heavy oil only. In KK-4C-A1, majority of HCFIs from Cannanore (Early Miocene) and Calicut (Early Oligocene) Formations appeared as bitumen like inclusions in annealed micro-cracks within the grains of quartz and feldspar of sandstone-claystone. Biphase HCFIs in annealed micro-cracks towards the lower depths were found in the diagenetic minerals of quartz and feldspar and calcite grains of sandstone, claystone and limestone of Kasaragod Formation only (Palaeocene to Early Eocene) and might get trapped along the micro-fracture by re-healing process. Laser Raman study of HCFIs within the study area throws light on the major constituents present in HCFIs. Raman peaks identified from the present study are benzene, bromobenzene, cyclohexane, SO_2, COS, H_2S, alkanes in HCFIs. A broad band for water and $CaCO_3$ peaks also observed from the studied samples. Palaeotemperature of coeval aqueous inclusions falling in the Oil window range supports the favourable thermal conditions was there for oil generation in K-K Basin. But, there is no further evidence for commercially viable hydrocarbon within the well. Lack of stratigraphic/structural trap or poor sealing and source rock richness and maturity content also could be the reasons for not having hydrocarbons in this non-productive well. The fluid inclusion study has the potential to ascertain the conditions of hydrocarbons in a sedimentary basin even if it is present in the micron-level quantities in the form of hydrocarbon bearing fluid inclusions. Hence, fluid inclusion techniques can act as a preliminary study tool for detecting oil in minute level which in turn provides valuable information on the probability of finding hydrocarbon in sedimentary basins.

Authors' Contributions

Silpa Thankan: Conceptualization, Methodology, Investigation, Writing-Original Draft, Formal Analysis. **V. Nanadakumar**: Conceptualization, Supervision, Reviewing and Editing, Investigation. **Shivapriya S.**: Reviewing and Editing.

Conflict of Interest

The authors declare that they do not have any conflict of interest or personal relationships that could have appeared to influence the work reported in this paper.

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