PREDICTION OF BIODEGRADATION AND BASIN MODELLING – A NEW INTEGRATED APPROACH

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Introduction :

In oil exploration, besides the evaluation of the volume of hydrocarbons in place, predicting the quality of the reservoired fluid is a critical issue for the evaluation of the petroleum interest of a new geological prospect. This prediction, which has to be done before drilling, is of paramount importance in deep offshore settings where the cost of exploration wells and field development imply that only production of large fields hosting good quality oil is economically viable. In this respect, the discovery of unexpected biodegraded heavy oils in some drilled offshore prospects has led the oil companies to strongly encourage research in tools and concepts which can help to avoid such a failure. IFP, which is largely involved in reservoir geochemistry and all the processes that control the chemical and physical properties of the entrapped oil and thus its API gravity, has developed geological concepts designed to predict biodegradation. The new approach, called BioTem, is aiming at estimating the biodegradation level of potential prospects from basin modelling results. It takes into account the bacterial behaviour, the depth of the prospect and the field filling scenarios provided by basin numerical model.

Background :

Horstad *et al.* (1992) was one of the first to develop a biodegradation model based on a study of the Gulfaks field (North Sea). This model considers a constant flux of hydrocarbons and water during the filling of the trap. The destruction of hydrocarbons is calculated with a first order kinetic law, the availability in electron acceptors and hydrocarbons being controlled by diffusion. Others, mainly for environmental purposes, have developed more complex models integrating a more accurate 3D description of the porous medium (SIMUSCOP; BIO1D, RT3D, PARSSIM1...). Unfortunately, these models are not well adapted to geological settings. Recently a new Biodegradation Index (BDI) has been proposed by Yu *et al.* (2002). This approach takes advantage of the numerical basin modelling outputs but needs an empirical basin-dependent parameter.

Modelling biodegradation - the BioTem approach :

Biodegradation is an alteration process due to bacterial activity which increases oil gravity, metal content, sulfur content, acidity and viscosity. Active biodegradation in petroleum reservoir requires some specific conditions (Head *et al.*, 2003): presence of bacteria, water, petroleum, and electron acceptors (O_2, and/or SO_4^{--}, NO_3^{-}…). These conditions are present at the OWC (Oil/Water contact) and it is now well accepted that this transition zone, when temperature and salinity are compatible with life (Bernard *et al.,* 1992), is the place where biodegradation takes place (Head *et al*. 2003). In our approach, biodegradation is supposed to be active at the OWC if the reservoir temperature is below 80°C during the trap oil filling time. This biodegradation "window" is detected from basin modelling outputs. The biodegradation level of the hydrocarbon fluid is controlled by the number of bacteria and their individual HC consumption rate. The method allows the mass of oil loss by biodegradation to be evaluated, e.g. the amount of hydrocarbons destroyed by biological action during the filling history of the field. The principle of the determination of the biodegradation level is to calculate the mass balance between the oil destroyed by biodegradation and the oil which would be in place without biodegradation. The calculation is divided into four steps: **Step 1**: selection from a numerical basin model results of the high saturation model cells which represent the reservoir of the trap on which biodegradation calculation will be performed. **Step 2**: estimation of the amount of hydrocarbons (M_{hp}) present in the field without biodegradation. This is calculated from the basin modelling using the following formula: $M_{hp} = S_m \times V_p \times \phi_m \times \rho_h$ where S_m is the HC saturation of the reservoir, ϕ_m is the reservoir porosity, ρ_h is the HC density and V_p is the reservoir volume. **Step 3**: estimation of the amount of oil destroyed by biodegradation in the field. It is based on the following rules: 1) biodegradation is active at the water/oil transition zone (OWC) only during the filling period of the field (Fig. 1 illustrates the supposed process which can lead to a highly biodegraded oil column); 2) biodegradation is active only if the field temperature is lower than 80°C at the time of the trap filling.

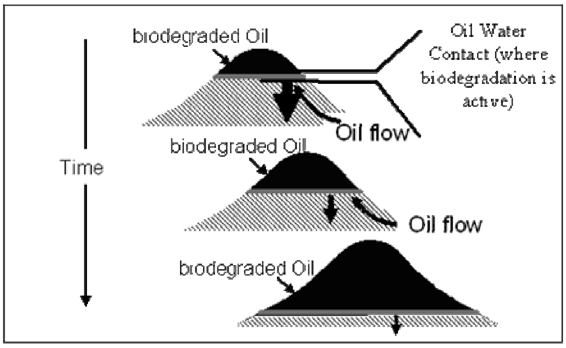

Figure 1

The mass of destroyed oil in the field is estimated using the following relation : $M_{hb} = \frac{N_{bact} \times E \times V_p \times C_{bact} \times T_r}{R_{ch}}$ where N_{bact} is the number of bacteria present in the water/oil transition zone calculated from the relation given by Cragg *et al.* (1999) $N_{bact} = 10^{(7.95-(0.64\times\log(Z_m)))}$ where Z_m is the depth of the reservoir, E is a "scale factor" (value around 0.02 to 0.04) representing the ratio between the height of the total oil column to the thickness of the water to oil transition zone (OWC). This factor is needed because basin modelling usually does not simulate the downward movement of the OWC during the filling history of the field but only the overall increase of the hydrocarbon saturation in the model cell(s) representing the field. V_p and T_r are respectively the volume of the reservoir and its filling time; C_{bact} is the average carbon consumption of a bacteria and is estimated around 10^{-11} to 10^{-14} µg of C per second (Larter *et al.* 2000) and R_{ch} is the mass ratio between carbon and hydrocarbon (usually taken equal to 0.8). **Step 4:** estimation of the biodegradation level. This is based on the following ratio: $R = \frac{\text{Mass of biodegraded oil}}{\text{Mass of oil without biodegradation}} = \frac{M_{hb}}{M_{hp}}$. Then, based on heavy metal content of biodegraded reservoired oil, it is possible to convert the R ratio into the Peters & Moldowan (1993) classical biodegradation level scale. The tentative following correlation is used :

$R \times 100$	0-10	11-50	51-60	61-75	76- 90	>91
Scale of Peter & Moldovan	1	2	3	4	5	6

Case study : This approach has been applied to a cross-section of the Potiguar Basin (Brazil) on which basin modelling was performed. An averaged filling time of 4 My was taken for each calculation. Figure 2 A shows the hydrocarbon saturation calculated by the model along the cross-section together with examples of the HC saturated gas chromatogram distribution of measured sampled oils. The clear decrease in the amount of *n*-alkanes demonstrates the increasing biodegradation level of the oils from offshore (right) to onshore (left). Figure 2 B shows the good fit, at the location of the samples, between the calculated R ratio using the BioTem approach and mass balance estimated from analytical oil data.

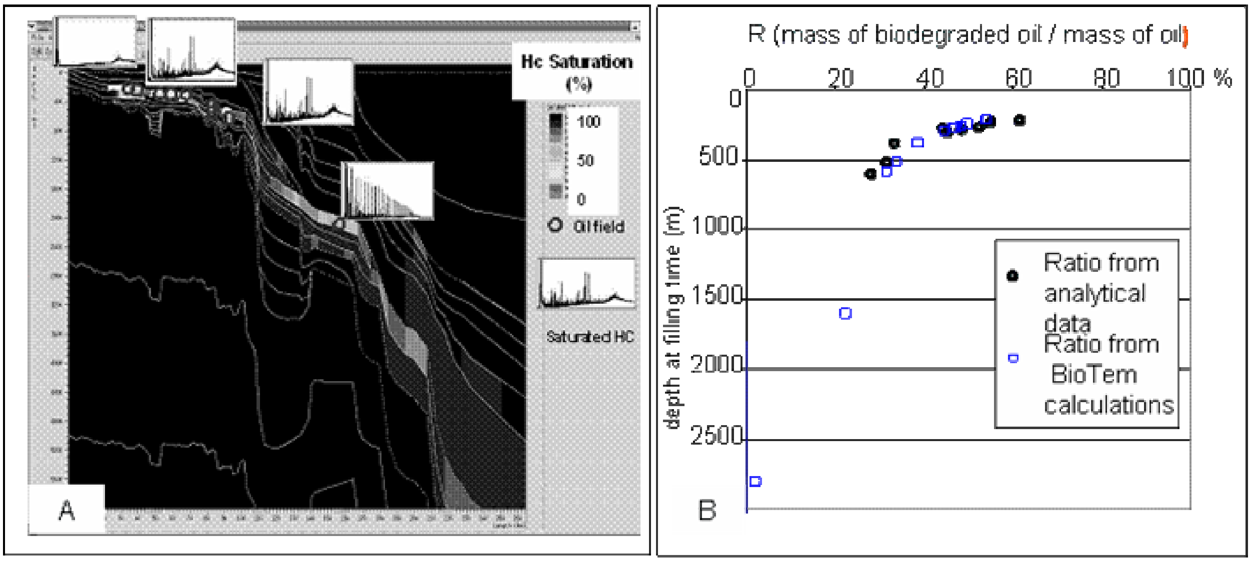

Figure 2

Conclusion : The proposed approach is aiming at estimating the biodegradation level from basin modelling results. It takes into account the bacterial behaviour, the depth of the potential prospect and the reservoir filling scenario provided by basin numerical modelling. The approach has been tentatively performed on the Potiguar Basin where a trend of biodegradation is well known. The comparison between the biodegradation level estimated from oil samples and the estimation using the presented BioTem method supports the potential of the approach to assess the biodegradation risk in exploration.

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