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Introducing a new smart tool for screening and addressing suitable CCS projects

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Abstract

Selection of most suitable sites, is one of most important factors for successful CO2 storage which generally is done by criteria obtained from geo science literatures or projects experiences. How ever projects owners or stockholders usually move to complete geophysical studies in order to finalize storage sites, access to smart tools and softwares could reduce the time and cost of project characterization then help decision makers to more better result.In the other hand, success of CCS projects related to economical factors mostly affected by source type of CO2 and site-source destination also.

In order to achieve this propose Rahbord Energy Alborz developed *CCS advisor* an user friend software which could be applied for suitable CCS projects . the software is equipped by either valid and updated data bases beside criteria obtained from last experiences . In addition , all the necessary correlations and calculations is performed by the software automatically. *CCS advisor* works based on parameters , engineering calculations , simulations , machine learning and statistical method . this new tool cover a chain of CCS projects capturing methods , capturing costs, transportation costs, site selection , revenue , storage capacity and operation problems which can be matched together.

This paper introduce *CCS advisor* , then comprise the results obtained from *CCS advisor* by the results originated from other software has been applied for EOR projects before.

The results shows that there is good match between *CCS advisor* reports and other known methods but the time and cost of preliminary studies could be reduced by apply *CCS advisor* dramatically.

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Keywords: Software; Screening; CCS;EOR ;CCS advisor ; site selection

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Introduction

According to increase in attraction of CCS as a one of important and effective solution for CO2 mitigation and at the same time , stabilizing of CO2 EOR as an essential method for enhanced oil recovery, attention to screening device for preliminary selection of suitable projects has been increased In the past decade.

Not all oil reservoirs are suitable for CO2 EOR and storage for various technical and economic reasons. So preliminary technical evaluations including: screening for EOR and storage suitability, technical ranking of suitable reservoir, and IOR and CO2 storage capacity predictions were suggested for selecting oil reservoir for CO2 EOR and storage before considering other economic criteria .These criteria are based on the optimizing reservoir performance for better IOR/EOR.

Although many operators considered CO2 injection is a technically proven EOR technique, which can be conducted in their fields if this is offered by a satisfactory financial return, there are still some technical concerns over the projects .

The main challenge, in terms of oil recovery, can be unfavorable reservoir characteristics causing poor sweep efficiency due to early CO2 breakthrough as a result of mobility contrast, gas override, and reservoir heterogeneity.

Some of the causes of CO2 flood failure in previous projects in Permian Basin and North Dakota included reservoir heterogeneity, low permeability, high water cuts and early CO2 segregation and channeling through natural fractures Well spacing is another factor that can cause CO2 EOR less effective.

CO2 related problems on facilities and in reservoirs have always been a noticeable challenge to oil industry and its great impact on project economics is well known.[1]

Alberta Research Council (ARC) developed *Select EOR* a computer method not only for screen suitable CO2 EOR projects but also for evaluating the enhanced oil recovery for petroleum reservoirs in 2009.

Select EOR , was an integrated PC based tool to assess technical feasibility potential EOR process from reservoir parameters and the current knowledge of EOR results . in initial evaluation stage select EOR perform a Go/ Not Go screening of EOR methods and in second stage , it generates predictions for screened process. [2]

In the other hand , *EOGUI* is a graphical user Interface for the United States of America, Department of Energy, National Energy Technology Laboratory, Publicly Available EOR Software. Through the use of this application, the user can quickly screen oil fields and quantify incremental production for potentially applicable EOR techniques.

This graphical user interface *(GUI)* application : Quickly screen and rank appropriate EOR methods for a given set of summary reservoir and fluid properties. Prepares the input files required for the technical analysis portions of the publicly available fortran applications. Namely, the GUI does not prepare the input required to calculate the economic analysis that is also available within these publicly available software.[3]

As it could be observed, simple and traditional screen tools in end at the start of 2000 ,never note to some other factors or don't have any emphasis on production problems. The screening of large number of reservoirs for the application of EOR processes has been generally done through "rules of thumb" which oftentimes fail to identify the most suitable reservoirs, due to their binary characteristics, which do not take into account synergistic effects on process performance for reservoir

Therefore, a new screening method is developed in *Rivas , Embid* and *Bolivar* work to rank reservoirs for carbon dioxide flooding which attempts to solve this shortcoming.

Their method was based on a parametric study, carried out systematically to determine the effect of reservoir properties on reservoir response to the gas injection. The study was done using a fully compositional simulator, a black oil model with a mixing parameter, and a semi-analytical predictive model.

Reservoir parameters examined were temperature, pressure, porosity, permeability, dip, API gravity, oil saturation, net oil sand thickness, minimum miscibility pressure, saturation pressure, remaining oil

in place, and reservoir depth. The optimum set of parameters which gave the best average oil production rate for a base case was obtained from the simulation studies. The base case consisted of the injection of 2000 MSCF/D of carbon dioxide in a inverted five spot, 40 acres pattern.

Rivas et al studies results 0.24 , 0.14 ,0.07 ,0.2, 0.19,0.02 and 0.11 respectively for API gravity , Temperature, Permeability , Oil Saturation , pressure to MMP ratio ,porosity , net reservoir thickness and dip degree. [4]

Neither ranking works nor traditional screening tools, haven't cover all shapes of CCS projects include source evaluation, transfer, storage and economical aspects of projects. In addition , ranking works just evaluated weight of factors in one single field or just could be assumed valid for that field and can not be generalized to other fields.

In the other hand , screening soft wares have extra emphasis on parameters criteria which may fail suitable reservoir is located binary condition. traditional screening tools do not consider some operational problems like early break trough , extra energy consumption also.

Consequently recently , new generation of smart tools were developed for CO2 EOR/ CCS projects screening which considered effect of oil price and Carbon tax too.

TNO has developed as part of the ECCO project a full CCS chain techno-economic evaluation tool. The tool includes a CO2-EOR module that is used to link CO2-EOR fields to the CO2 infrastructure.

ECCO Tool is a software program designed to evaluate quantitatively the post-tax economics of Carbon Capture and Storage (CCS) projects for each of the various mutually dependent actors along the CCS value chain. The tool enables the user to study how to "close the chain", i.e. to find out which case study definitions result in a "business case" for each actor along the chain. Actors may have contractual arrangements specifying their rights and obligations with the other actors in the value chain. These contracts have financial implications in order to promote a fair risk vs. reward distribution among the actors in the value chain.

CCS value chains consist in the *ECCO* Tool of various user-defined combinations of CO2 sources like power plants and other industrial plants, various modes of transportation like pipelines or ship, and various types of CO2 storage facilities like depleted oil fields for CO2-enhanced oil recovery, depleted gas fields, and aquifers.

Almost at same time , *MEC (Miscible EOR Consultant)* is a new smart tools for screening suitable reservoirs and select best miscible gas injection process developed by Rahbord Energy Alborz in 2013-2014, classify the most effective method for miscible EOR . *MEC* also can sort Miscible EOR methods according efficiency .it reports oil recovery , break trough time , forecast operation problems.

The MEC is more flexible about parameter criteria with an update in CO2 EOR criteria according to using new successful CO2 EOR experiences . in addition , smart evaluation and updating in screening criteria is performed by *MEC* automatically. Another advantage of *MEC* in comparison of traditional screening tools are ability of this software for calculation and prediction of probability of CO2 EOR success .

CCS advisor originated from modification and basic upgrading in *MEC* to apply in all CCS project screening and assess.*CCS advisor* covers all storage shapes include CO2 EOR, EGR , coal bed methane and saline formation. It must mentioned that all type of important stationary sources power plants, iron & steel , cement factory also petrochemical plants are considered by *CCS advisor.*

the software is equipped by either valid and updated data bases beside criteria obtained from last experiences . In addition , all the necessary correlations and calculations is performed by the software automatically. *CCS advisor* works based on parameters , engineering calculations , simulations , machine learning and statistical method .

By performing more applied and analytical assessment , *CCS Advisor* overcomes problems results from uncertainty of binary value of reservoirs and report more detail results which allows operators make better decision.

this new tool cover a chain of CCS projects capturing methods , capturing costs, transportation costs, site selection , revenue , storage capacity and operation problems which can be matched together.

This paper explains *CCS advisor* design basis , operation procedure and algorithm , how dose it work , results is obtained from *CCS Advisor* and its advantages.

In order to show and compare the results of *CCS Advisor* , an known CO2 EOR case study has been choose and presented in current paper. A small low permeable oil field were put under CO2 flooding and studied with *Select EOR, Eclipse 300* and *CCS Advisor* respectively then results from different software were compared.

CCS Advisor **Design and Operating Basis**

CCS Advisor were developed both for network user and single user PC . the software is equipped by either valid and updated data bases beside criteria obtained from last experiences . all the necessary correlations and calculations is performed by the software automatically. *CCS advisor* works based on parameters , engineering calculations , simulations , machine learning and statistical method .

Full information of parameters from 68 successful CO2 EOR projects were put in the data base of CCS Advisor. Rock Type, fracturing statue , Porosity, Depth, fracturing pressure, fluid type , oil in place, API , reservoir temperature , reservoir pressure, water saturation , average permeability, residual oil saturation, pore volume, MMP, crude composition, C7+ molecular weight ,injection well type , injection rate, injection pattern , production rate before injection, production rate after injection all studied for using in *CCS Advisor* data base.

The *CCS Advisor* data base could be updated due to new experiences and results so an algorithm were put on software to obtain criteria from data base automatically. Thus the software screen suitable reservoirs by two method both fixed default criteria and dynamic criteria .One of gaps of traditional screening tools , were report fail some suitable reservoirs which just hasn't met one of criteria with neglect able and binary difference.
Among the disadvantages of the conventional screening procedures one can mention: Since the comparison is done stepwise similar reservoirs are classified differently. Thus a 30 ° API reservoir is selected while one with 29 ° API is rejected. Due to the binary characteristic of the procedure, synergistic effects are not taken into account. For example, a reservoir with properties slightly within criteria is selected over a reservoir with very good values in all properties but one. The weights or importance assigned to each parameter are very subjective.[4]
MEC and *CCS Advisor* both overcome mentioned disadvantages with use two different manner of screening one is based on more emphasis on MMP and another one emphasis on MMP and summation of effective parameters weight. It is observed that some reservoirs hasn't met successful EOR criteria but in practice , successful CO2 EOR were reported .

Table 1. CO2 EOR fixed criteria used in *CCS Advisor*.

Effective Parameter	Criteria
Depth	800 Meter
Reservoir Temperature	25 C
Oil Density	820 Kg /m^3
Viscosity	10 mPa.s
Oil Saturation	0.25

MEC and *CCS Advisor* use valid and choose best correlations for calculating minimum miscibility pressure (MMP). Both soft wares evaluate data value and choose best correlation for MMP calculation .
CCS Advisor were designed in user friend manner which makes able user to obtain maximum results from minimum data enter.
Soft ware use correlation and equation for calculation viscosity ,mobility ratio, fracturing pressure, CO2 density in reservoir condition in addition to MMP in case user doesn't have access to exact value .
However a reservoir might be passed from screening criteria but it may that CO2 EOR face with so many operation problems. Either *MEC* or CCS *advisor* report some warning when unfavorable problems may occur during flooding process. Early break through , energy penalty, oil trapping and temporary miscibility , gas floating and asphaltic component production are operational problems are warned by CCS Advisor.
Unfavorable ratio of vertical to horizontal permeability results segregation and upward CO2 moving so it must be avoided, the soft ware warns about this problem by *gas floating* report.
According to successful experiences and comprise reservoir data with data base information, the software reports success probability .
CCS advisor covers all storage shapes include CO2 EOR, EGR , coal bed methane and saline formation. It must mentioned that all type of important stationary sources power plants, iron & steel , cement factory also petrochemical plants are considered by *CCS advisor*.
All production process with updated emission factor and CO2 concentration in stack gases were put in *CCS Advisor* and according each category of composition and flow rate of gas, capturing plant simulated inside the software , so capturing process were selected when user illustrate the industry and production rate.
The same calculation is done for transportation side which calculate pipe line characteristic in addition compressor or pump station recommended capacity. As a state of art *CCS Advisor* can find nearest experience either with combination of more than one projects or single case to compare and forecast ongoing project result . For CO2 EOR cases , ultimate oil recovery and gas break trough time will be estimated and reported by the software also.

Reports and results from software:
In order to compare *CCS Advisor* results with simulator report , a low permeable small oil field has been choose and CO2 flooding studied in this case. NM1 field is a low permeability reservoir located in middle east and was explored in 1969. The oil in place is estimated about 849 MMbbl with 5% recovery factor , 41 MMbbl could be produced. Production area is about 24400 Acer and production depth is 5729 feet under ground level . Reservoir contains

carbonated fractured rock with average porosity 7 and water saturation 35% , gas cap drive and gas solution drive are assumed as main mechanism for oil production.
Current pressure is 2090 PSI but reservoir saturation pressure reported as 1850 PSI. The reservoir contains light oil with API 45.8 and started to production from 1990 with rate 1900 bbl per day which decreased to 1700 bbl per day in 2005.Up to end of 2005 , more than 9.5 MM bbl which is equivalent of 23 % of recoverable oil in place, has been produced in addition to 5.5 billion cubic feet gas.
According to predictions, production rate will fall below 1200 bbl per day before 2028 and new drilling can not be helpful because of reservoir low permeability.[5]
Flooding for three gases CO2 , Nitrogen and dry methane has been simulated and studied in NM1 . reservoir simulation shows that Methane and Nitrogen injection in this field never rise to miscible condition. In addition Nitrogen and Methane injection meet early break trough even in low injection rate 5 MMSCFD and 10 MMSCFD.
The same results is obtained from MEC the specific software for miscible EOR evaluation.

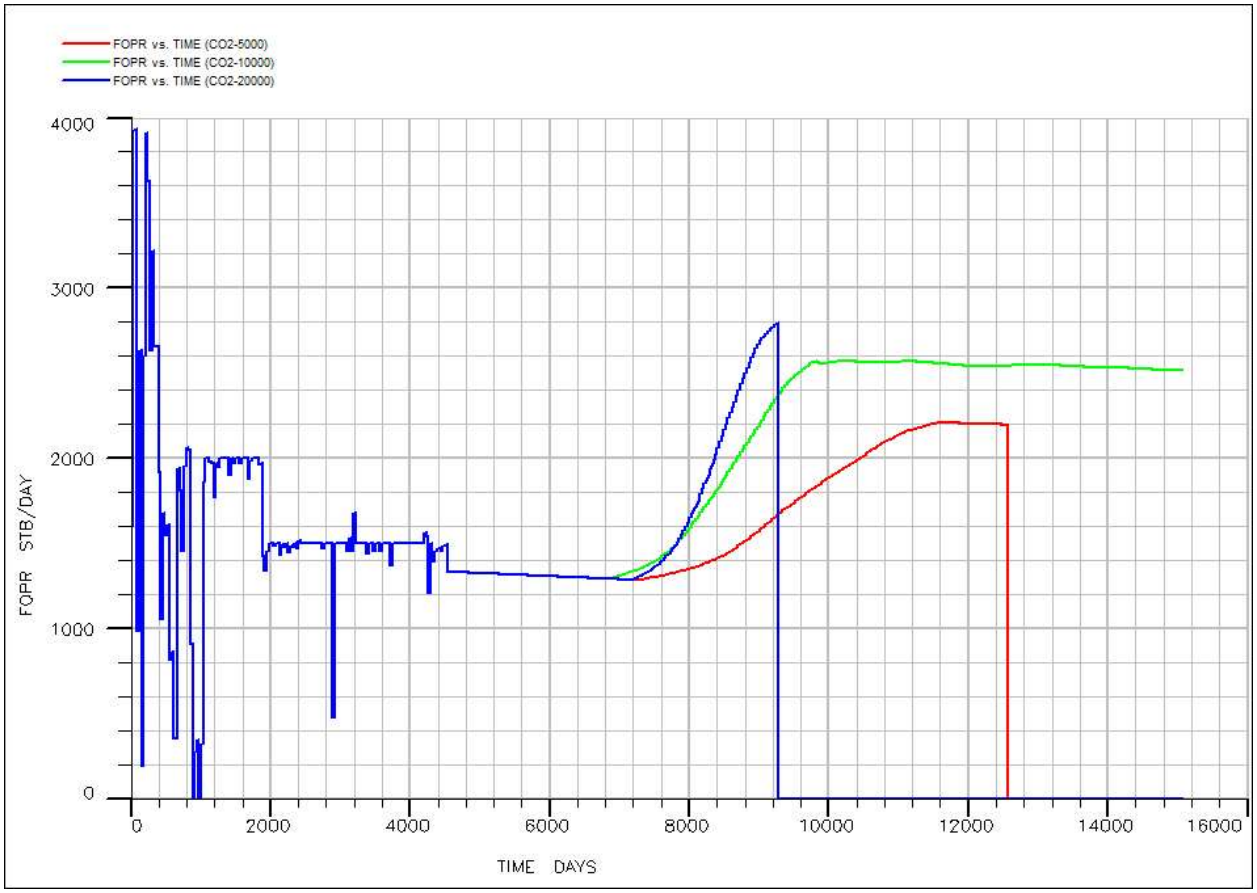

Fig. 1. CO2 injection simulation results in 3 scenario 5MMSFD (red line)10MMSCFD(green line)and 20MMSCFD(blue line)

Injection of CO2 can could meet miscible condition in this reservoir. The result of simulation for CO2 flooding for 20MMSCFD shows increase in oil production up to 2800 bbl per day but break trough after almost 2000 days after start of injection.
As it could be seen in table 2 , MEC (CCS advisor EOR majul) fail Nitrogen and Methane miscible EOR because these method couldn't met soft ware criteria for miscibility . Nitrogen MMP is predicted 9278 PSI and MMP for methane is estimated 4551 PSI so much above reservoir initial pressure 2130 PSI .it makes Nitrogen and Methane miscible injection impossible as understood from simulator too. Miscibility pressure of CO2 , predict by soft ware

2085 PSI which is near by reservoir current pressure and is below reservoir initial pressure . according to *CCS Advisor* logic, when CO2 miscibility pressure is more than reservoir current pressure but still less than reservoir initial pressure , the reservoir is judged appropriate for CO2 injection in case there is an active water mechanism.

Table 2. scoring of miscible injection methods by MEC

Inject Gas	Miscible injection Result	Score
CO2	Pass	4.262
Nitrogen	Fail	0
Methane	Fail	0

CO2 EOR can pass criteria of Miscible injection both in *MEC* and *CCS Advisor* but just earn score 4.262 from maximum 10. It expects medium to low efficiency of CO2 EOR which confirmed with simulation results.
CCS Advisor predict 71.9 probability for CO2 EOR success but it warns about early break trough problem too. definitely what will happen in practice is predicted by *CCS Advisor* .
Production index is obtained from CCS Advisor shows 0.208 of movable oil at the end of injection time how ever dose not match with simulation report but narrates low sweep efficiency in comparison of other more permeable fields and productive reservoirs according to their higher production index values.
In this case study , *CCS Advisor* brilliant prediction about both gas break through time and CO2 practical storage capacity. Maximum theoretical storage capacity[6] , could be obtained from equation,

$$MCO2t = \rho CO2 * [Rf * A * h * \varphi * (1-Sw) - Viw + Vpw)$$

Which Rf , A, h, φ, Sw, Viw , Vpw are recovery factor, reservoir area, reservoir thickness, porosity, water saturation, valium of water injected and produced respectively. Actually this capacity never could be achieved because of reservoir characteristics , uncertainty, tectonic condition, channeling , low permeability , heterogeneity and incomplete mobility .just part of maximum theoretical storage capacity is used in practice.
In this case however maximum theoretical capacity is assumed 57.38 Million tons , but simulation result expects that just 3.4% of this huge capacity could be available because of early break trough.
Early break trough time is obtained 1800 days after CO2 injection from simulation and is estimated 1630 days after injection which shows almost excellent matching . in the other hand CO2 storage capacity is calculated 1.792 million tones by *CCS Advisor* which is reported 1.92 million tones by Eclipse 300.

Table 3 results of break trough time and CO2 storage capacity obtained by CCS Advisor and reservoir simulator

Inject Gas	CCS Advisor	Simulation	Difference
CO2 Storage Capacity Million Ton	1.792	1.921	6.7%
Early Break trough time day	1630	1800	9.4%

Conclusion :
With considering screen the criteria, storage capacity estimation, oil production value, break trough time , unfavorable operational problems , evaluation of capturing plant and cost and finally transportation facilities, *CCS Advisor* provide best consulting for every operators.
About production and increase in oil recovery , how ever CCS Advisor dose not predict exact value according to quantity , but its results provide valid qualitative consulting which address EOR over view very good.
Prediction of early break trough time and CO2 storage capacity really could be described as state of art of *CCS Advisor* which just have neglect able variance from simulation results. It is clear that CCS projects still is not usual in all countries thus in order to urge industries , investors , governments and decision makers , to perform projects more rapidly , a trustable smart tool is required .
How ever engineering studies never could be replaced by the *CCS advisor* but develop a suitable software for CCS projects , could be described as effective step to short cutting decision making time at same time with efficient accuracy.

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