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Universitas Pembangunan Nasional "Veteran" Yogyakarta

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# DAFTAR ISI

<table>
<thead>
<tr>
<th>BAGIAN</th>
<th>ISI</th>
</tr>
</thead>
<tbody>
<tr>
<td>KATA PENGANTAR</td>
<td>iii</td>
</tr>
<tr>
<td>SAMBUTAN DEKAN FAKULTAS TEKNOLOGI MINERAL</td>
<td>iv</td>
</tr>
<tr>
<td>SAMBUTAN REKTOR UPN &quot;VETERAN&quot; YOGYAKARTA</td>
<td>v</td>
</tr>
<tr>
<td>DAFTAR ISI</td>
<td>vii</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KELOMPOK ENERGI</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PROBLEMA PENGENBANGAN ENERGI TERBARUKAN UNTUK MENDUKUNG PROGRAM ENERGI LISTRIK 35.000 MW KUSNARYO</td>
<td>2</td>
</tr>
<tr>
<td>2 KAJIAN INITIAL OIL IN PLACE RESERVOIR X BERDASARKAN DATA RESERVOIR DAN DATA PRODUKSI Dyah Rini RATNANINGSIH, Dedy KRISTANTO, Sindu Fitra Kumara Aji</td>
<td>9</td>
</tr>
<tr>
<td>3 PENGEMBANGAN STRUKTUR BIMA DALAM UPAYA PENINGKATAN PRODUKSI WIBOWO, Edgie Yuda KAESTI</td>
<td>20</td>
</tr>
<tr>
<td>4 OPTIMASI PRODUKSI BROWNFIELD LAPANGAN “O” Mia Ferian HELMY</td>
<td>31</td>
</tr>
<tr>
<td>5 PENINGKATAN KAPASITAS BLOCK STATION DI STRUKTUR GIRI Edgie Yuda KAESTI, HARYADI</td>
<td>37</td>
</tr>
<tr>
<td>6 PENGGUNAAN TEKNOLOGI MICROWAVE UNTUK COAL UPGRADING Rengga Ade SAPUTRA</td>
<td>45</td>
</tr>
<tr>
<td>7 GASIFIKASI AWAL PADA BATUBARA PERINGKAT RENDAH TANJUNG ENIM, SUMATERA SELATAN MENGGUNAKAN REAKTOR UNGGUN TERFLUIDISASI Edy NURSANTO, Tutik MUIJ S., I Gusti S.BUDIAMAN, Gogot HARYONO, Bambang SUGIARTO, Purwo SUBAGYO</td>
<td>50</td>
</tr>
<tr>
<td>8 PENGGUNAAN INFORMASI TEKNOLOGI SEBAGAI KUNCI KEBERHASILAN KEGIATAN AWAL EKSPLORASI ENERGI PANASBUMI Herry RISWANDI</td>
<td>55</td>
</tr>
<tr>
<td>9 PENGARUH PENGGUNAAN KATALIS NIKEL TERHADAP PRODUK GASIFIKASI BATUBARA PERINGKAT RENDAH Agus TRIANTORO</td>
<td>63</td>
</tr>
<tr>
<td>10 PERCAMPURAN BATUBARA UNTUK MENDAPATKAN BATUBARA PENGOKAS KUALITAS BAIK MELALUI ANALISIS FSI DAN PETROGRAFI Yudho Dwi GALIH, Diana Irmawati PRADANI, Ratih Hardini Kusima PUTRI, Heru DWIRIAWAN</td>
<td>71</td>
</tr>
</tbody>
</table>
11 OPTIMASI TEKANAN KEPALA SUMUR PADA LAPANGAN PANASBUMI X CLUSTER Y
Eko Widi PRAMAUDIOHADI, Kharisma MUSLIMIN .................................................. 78
12 OPTIMASI INJEKSI SURFAKTAN PADA LAPANGAN BATU PASIR DENGAN MINYAK RINGAN
Indah WIDIYANINGSIH, Boni SWADESI ................................................................. 95
13 COMBINING HOT WATER INJECTION-SOLVENT AND ELECTROMAGNETIC HEATING FOR INCREASING RECOVERY FACTOR IN HEAVY OIL RESERVOIR
SURANTO .................................................................................................................. 103
14 STUDI PENGURSANA MINYAK TAHP LANJUT MENGGUNAKAN STIMULASI VIBRASI
Harry BUDIHARJO S ............................................................................................. 112
15 EXPERIMENTAL STUDY : CHEMICAL SYNERGISM IN CONCOCTING SURFACTANT FORMULATION FOR LOW SALINITY RESERVOIR
Ratna WIDIYANINGSIH, Ivan EFRAIZA ................................................................. 121

KELOMPOK GEOLOGI – EKSKLORASI ..................................................................... 127

1 ANALISIS MINERAL LEMPUNG PADA BATUAN ALTERASI SUMUR KMJ-26
LAPANGAN PANAS BUMI KAMOJANG JAWA BARAT
D.P YUDIANTORO, Emmy SUPARKA, Isao TAKASIMA, Daizo
ISHIYAMA, M. Yustin KAMAH dan Intan P. HATY .................................................. 128
2 PERTANDINGAN AKURASI METODE IDW DAN ORDINARY
KRIGING TERTANAP SUMBERDAYA NIKEL LATERIT - 2D
GUSKHANA, Yohanes T. SAGISOLLO, Romzi Rio WIBAWA ................................. 135
3 ANALISIS PENAKISIRAN SUMBERDAYA NIKEL LATERIT-3D
MENGGUNAKAN METODE BLOCK KRINGING
GUSKHANA, Waterman S. BARGAWA ................................................................. 142
4 PERATURAN DAERAH UNTUK BIMBINGAN TEKNIS EKSKLORASI DAN
EKSPLOITASI MINERAL DAN PENDAPATAN DI DAERAH, STUDI KASUS DI DAERAH PENAMBANGAN EMAS PINANGKABAN, GUMELAR,
KABUPATEN BANYUMAS, JAWA TENGAH
Heru Sigit PURWANTO, Harry RISWANDI ......................................................... 150
5 PEMODELAN TINGKAT AKTIVITAS SESAR BERDASARKAN ANALISIS
DEFORMASI MENGGUNAKAN PENGAMATAN GPS
Joko HARTADI, Sugeng RAHARJO, Oktavia Dewi ALFIANI ................................ 158
6 PENENTUAN SESAR AKTIF BERDASARKAN DATA GEODETIK DAN
INTERPRETASI GEOLOGI SEKITAR SUNGAI CIMANDIRI JAWA BARAT
Sugeng RAHARJO, Joko HARTADI, Oktavia Dewi ALFIANI ................................. 165
7 ANALISA CITRA SATELIT PENGINDERAN JAUH UNTUK PEMETAAN GEOLOGI SUATU WILAYAH
Hendra BAHAR ....................................................................................................... 172
8 PENDEKATAN METODE GIS TERHADAP OPTIMASI SUMBERDAYA SISA
BATUBARA DAN PEMANFAATAN LAHAN BEKAS TAMBANG
Mohamad ANIS, Arifudin IDRUS, Hendra AMIAYA ............................................... 177
SIKUEN STRATIGRAFI LAPANGAN “Y” SUB CEKUNGAN JATIBARANG CEKUNGAN JAWA BARAT UTARA BERDASARKAN DATA LOG SUMUR “P-01”

Pontjomojono KUNDANURDORO, Nur Arief NUGROHO

186

KARAKTERISTIK MINERALISASI VEIN PERMUKAAN PADA SISTEM EPITEMPAL SULFIDASI RENDAH DAERAH TATAPAAN, KABUPATEN MINAHASA SELATAN, SULAWESI UTARA

Hari Wiki UTAMA, SUPRAPTO, SUTANTO

200

CHARACTERISTIC OF THE FLUID INCLUSION IN QUARTZ VEINS AT TEH RANDU KUNING PORPHYRY Cu-Au DEPOSIT, SELOGIRI, CENTRAL JAVA

SUTARTO, Arifuddin IDRUS, Agung HARJOKO, Lucas Donny SETIJADJI, Michael MEYER, Rama DAN

208

ANALISA POTENSI SPILL OUT MENGGUNAKAN METODE RESISTIVITAS PADA AREA PANEL 3 NORTH TAMBANG BAWAH TANAH KABUPATEN MIMIKA PROVINSI PAPUA

Wahyu HIDAYAT, Wisnu HARYANTO

221

KLANG GATES QUARTZ DYKE (MALAYSIA) AS A POTENTIAL WORLD HERITAGE SITE

Achmad RODHI, Mohd Shafeea LEMAN, Lim Choun SIAN

229

ANALISA KEGAGALAN PENANGGULANGAN KICK DAN TERJADINYA UNDERGROUND BLOWOUT PADA SUMUR EXPLORASI X

HERIANTO

235

ANALISA SWELLING CLAY FORMASI TELISA UNTUK PERENCANAAN LUMPUR PEMBORAN

HERIANTO, Djoko ASKEYANTO

244

ANALISA MULTIATTRIBUT SEISMIK DAN GEOSTATISTIK VARIOGRAM UNTUK DISITRIBUSI POROSITAS RESERVOIR BATUPASIR LAPISAN "X" LAPANGAN "BERU" FORMASI BEKASAP CEKUNGAN SUMATERA TENGAH

Ardian NOVIANTO, Nur Arief NUGROHO

254

PENGARUH KARAKTERISTIK KIMIA AIR PADA FORMASI BALIKPAPAN DAN KAMPUNGBARU PADA TAMBANG BATUBARA, DAERAH KUTAILAMA KEC. ANGGANA, KAB. KUTAI KARTANEGERA

Ibnu HASYIM, Heru HENDRAYANA, Arifuddin IDRUS

266

KELOMPOK PENAMBANGAN

285

1 EVALUASI PRODUKSI ROTARY DRILL CP-650 PADA JENJANG 6m DAN 12m UNTUK MENGHASILKAN LUBANG TEMBAK DENGAN METODA STANDAR DEVIASI

Tri Gamela SALDY, Yohanes JONE, Muhammad Taufik AKBAR, Gunawan DJAFAR

286

2 OPTIMALISASI KERJA ALAT GALI MUAT DAN ALAT ANGKUT UNTUK PENINGKATAN PRODUKSI NIKE

Yohanes JONE, Muhammad Taufik AKBAR, Jose Ines D. PINTO, Gunawan DJAFAR

294
3 PENENTUAN PANJANG BOLT UNTUK SISTEM PENYANGGAAN TAMBAH BAWAH TANAH PADA LUBANG BUKAAN Cikoneng Decline TAMBANG BIJIH EMASPT. CIBALIUNG SUMBERDAYA BANTEN
Adriel ADHAREZA, Barlian Dwi NAGARA, Singgih SAPTONO

4 ANALISIS RANCANGAN TEKNIS PENAMBANGAN BATUBARA DI PIT 3 PT XYZ KAB. KAPUAS PROVINSI KALIMANTAN TENGAH
Indra SULISTYANTO, FERDINANDUS

5 EVALUASI PELEDAKAN BERDASARKAN DIGIBILITY DAN PRODUKTIVITY ALAT GALI MUAT PC-2000 PADA PIT NORTH PT. SAPTAINDRA SEJATI JOBSITE ADMO TUTUPAN, KALIMANTAN SELATAN
FERDINANDUS, Indra SULISTYANTO

6 PERAN SEKTOR INDUSTRI DALAM PEMBANGUNAN YANG BERKELANJUTAN
Sri Rahayu BUDIANI

7 ANALISIS PENYANGGA (WELD MESH) PADA LUBANG BUKAAN TAMBAH BAWAH TANAH PT. X, DI PROVINSI PAPUA
Cakra ANUGRAH, Eri PRABOWO

8 ANALISIS TEBAL SILL PILLAR PADA TAMBAH EMAS BAWAH TANAH PADA PT.XYZ DI PROVINSI LAMPUING
Eri PRABOWO, Cakra ANUGRAH

9 KAJIAN SISTEM PENYANGGAAN PADA PENAMBANGAN EMAS RAKYAT DI DESA CIHONJE
Reny KURNIAWATI

10 SEKTOR PERTAMBANGAN DAN PENGGALIAN SEBAGAI PENDORONG PERTUMBUHAN EKONOMI KABUPATEN KULONPROGO, DAERAH ISTIMEWA YOGYAKARTA
Aldin ARDIAN, HARTONO, Yasser TAUFIQ, Arno EDWIN

11 HARMONISASI IMPLEMENTASI UU NO. 23/2014 DENGAN UU NO. 4/2009 TERKAIT PENGELOLAAN USAHA PERTAMBANGAN MINERAL DAN BATUBARA
Anton SUDIYANTO, Untung SUKAMTO, Dyah PROBOWATI

12 KAJIAN KARAKTERISTIK MINERAL ALOFAN PADA MATERIAL KOLUVIAL DI DIENG JAWA TENGAH
Sahat HUTAHAEN, Indun TITISARIWATI

13 APLIKASI STRUKTUR GEOLOGI UNTUK OPTIMALISASI BLASTED MATERIALS KUARI BATUGAMPING KABUPATEN TUBAN, PROVINSI JAWA TIMUR
Avellyn Shinthya SARI, Fachrur Reza ASSEGAFF, DP. Waluyo ADJIE, Debi Yulian ADINATA

14 KAJIAN DESIGN TAMBAH UNTUK PELAKSANAAN PERUBAHAN DOKUMEN ANDAL PT.BINA INSAN SUKSES MANDIRI DI WILAYAH KECAMATAN MOOK MANAAR BULATN KABUPATEN KUTAI BARAT – KALIMANTAN TIMUR
Ervina FITRIYANI, Ika WIRANI
15 HUBUNGAN PERUBAHAN KOHESI, UNIT WEIGHT, DRY DENSITY DAN SATURATED DENSITY TERHADAP FAKTOR KEAMANAN PADA BATUAN SANDSTONE DI AREA PERTAMBANGAN BATUBARA DAERAH BENGALON, KALIMANTAN TIMUR
Muh. Arif IDHAM

KELOMPOK LINGKUNGAN

1 DETAIL ENGINEERING DESIGN REKLAMASI LAHAN PASCATAMBANG DI DAERAH KABUPATEN BANYUMAS
Waterman S. BARGAWA

2 KAJIAN REKLAMASI DAN EVALUASI LAHAN PADA LAHAN BEKAS TAMBANG BATUBARA DI PT.X DI KALIMANTAN TIMUR
Dedy MARGIANMOKO, Yos David INSO

3 KETERSEDIAAN SUMBER DAYA AIRTANAH DI KOTA SURAKARTA
Puji PRATIKNYO

4 KAJIAN PENGARUH PROSES REKLAMASI TERHADAP MATERIAL DISPOSAL BERDASARKAN PARAMETER UJI SIFAT FISIK, UJI SIFAT MEKANIK DAN UJI KOMPAKSI PADA TAMBANG MUARA TIGA BESAR SELATAN DI PT. BUKIT ASAM (PERSERO), Tbk
Yohanes T. SAGISOLLO, GUSKARNALI

5 PENILAIAN TINGKAT KEBERHASILAN REKLAMASI LAHAN BEKAS TAMBANG PIT 1 PT. PIPIT MUTIARA JAYA DI KABUPATEN TANA TIDUNG KALIMANTAN UTARA
A.A Inung Arie ADNYANO, Hepryandi Luwyk Djanas USUP

6 RENCANA REKLAMASI TAMBANG BATUBARA DI PT. RIMAU ENERGY MINING
Anton Yudi Umsini PUTRA, Barlian DWINAGARA, Muhamad Rizkiansyah ZULFAHRI, Prasodo Datu PRABANDARU

7 PENENTUAN STATUS MUTU AIR PERMUKAAN PADA LAHAN PASCA TAMBANG EMAS RAKYAT DI WILAYAH HAMPALIT KABUPATEN KATINGAN PROVINSI KALIMANTAN TENGAH
Hepryandi Luwyk Djanas USUP, A.A Inung Arie ADNYANO

8 ANALISIS KESESUAIAN LAHAN PERTAMBANGAN PADA IZIN USAHA PERTAMBANGAN (IUP) KABUPATEN KATINGAN PROVINSI KALIMANTAN TENGAH
Yos David INSO, Dedy MARGIANMOKO, Andre Geovanny KALENSUN

9 IDENTIFIKASI KUALITAS UDARA AMBIENT DAN AIR PERMUKAAN KEGIATAN PENAMBANGAN BATUBARA PT. ABC KABUPATEN BULUNGAN KALIMANTAN UTARA
Muhammad BUSYAIRI

10 PENGARUH SISTEM PENIRISAN PASIR (DRAIN HOLE) TERHADAP FLUKTUASI MUKA AIR TANAH, TAMBANG TERBUKA GRASBERG
Tedy Agung CAHYADI, Lilik Eko WIDODO, Sudarto NOTOSISWOYO, Ivan WAROMI
11 ANALISA POTENSI TANAH LONGSOR BERDASARKAN STUDI AIR TANAH DAN BIDANG GELINCIR MENGGUNAKAN METODE GEOLISTRIK DAN SEISMIK REFRAKSI
Wrego S. GIAMBORO, SUHARSONO, Ajimas P. SETIAHADIWIBOWO .................................................................................................................. 505

12 PENGAJIAN RISIKO BENCANA PARTICIPATIF UNTUK TATA KELOLA KAWASAN RAWAN BENCANA
Eko Teguh PARIPURNO, Bambang SASONGKO, Sari Bahagiarti KUSUMAYUDHA, Djoko MULYANTO, Puji LESTARI, Arif Rianto Budi NUGROHO, Aditya Pandhu WICAKSONO .......................................................... 513

13 PENENTUAN JARAK MAKSIMUM PEMASANGAN BORE HOLE PUMP PADA TAMBANG BAWAH TANAH TOGURACI PT. NUSA HALMAHERA MINERALS, PROVINSI MALUKU UTARA
Krisna MULYANA, Hasywir Thaib SIRI, INMARLINIANTO ................. 519

14 PERCOBAAN AWAL DOSIS PENGAPURAN PADA AIR ASAM TAMBANG DI KOLAM PENGENDAPAN LUMPUR PT. TRUBAINDO COAL MINING, KALIMANTAN TIMUR
Edy NURSANTO, Basuki RAHMAD, Edyanto ........................................... 528

15 PERTAMBANGAN DAN LINGKUNGAN
INMARLINIANTO, HARTONO ..................................................................... 533

16 KONDISI SOSIAL EKONOMI MASYARAKAT SEKITAR LAHAN PASCA TAMBANG BATUBARA DI KABUPATEN KUTAI KARTANEGARA KALIMANTAN TIMUR STUDI KASUS DI KECAMATAN TENGGARONG SUJIMAN ..................................................................................................................... 542

UCAPAN TERIMAKASIH ................................................................................. 558
COMBINING HOT WATER INJECTION-SOLVENT AND ELECTROMAGNETIC HEATING FOR INCREASING RECOVERY FACTOR IN HEAVY OIL RESERVOIR

SURANTO
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Abstract

The use of electromagnetic-heating methods in reducing heavy oil viscosity, until now, is not popular as steam injection methods, although it has been researched, possibly since 1986 by Hiebert. The first virgin application in the field was in 1988, Spark Formation in the Frog Lake area. However, this method in our present time is underused, even though its technology is environmentally friendly and space efficient. This research aims to build an optimized model for an electromagnetic-heating method, combined with hot-water. The electromagnetic-heating will expand the reservoir fluid volume but is still not enough for reservoir pressure maintenance. On the other hand, if too much water is injected, the water will absorb most of the heat, causing the heating of oil to be decreased. In this case, water will be used to transfer energy from electrical to the oil.

In this study, the combination of hot water and electromagnetic-heating of Duri heavy oil was analyzed by CMG Stars. The model was built with a seven-spot well inverted pattern, where distance between wells is at around 246 ft, and the injection well was placed in the center. The sensitivity parameters tested were hot water injection rate power of electromagnetic-heating.

From the base-case model, it was shown that electromagnetic-heating method produces about 2.5% OOIP (due to the reservoir pressure being very low). However after further study, the optimum case, a combination of electromagnetic-heating coupled with hot-water, was able to increase the recovery factor to about 37% of OOIP. Moreover, this study has shown that the oil density is a dominant factor which affects the oil recovery.

Keywords: electromagnetic-heating, heavy oil, hot water injection, reservoir simulation.

Abstrak


Keyword : electrical heating, heavy oil, water injection, solvent, reservoir simulation.
INTRODUCTION
The key of heavy oil and bitumen producing is reducing of viscosity. There are some methods to reduce oil viscosity such as steam injection, hot water injection, cyclic steam injection, and the others. The electrical heating is one of the ways to reduce viscosity. AD. Hiebert et.al (1986) have made electrical heating formula for numerical model. Electromagnetic heating technique is to heat the reservoir by means of the ohm losses of electrical current flowing in the connate water and the oil of the reservoir. The research is to build electrical heating which needs power, voltage and frequency. This case uses low-frequency (60-Hz [60-cycle/sec]). Electrical excitation of the formation must be specified as constant voltage, power, or current level. The electrical conductivities, heat capacities, and thermal conductivities of the various physical model media, together with the model geometry and appropriate voltage, current or power level, are entered into the simulator. This research uses MEGAERA numerical simulator after modified. Furthermore, the CMG simulator specially stars module is added the Hiebert’s formula⁶. In 2008, Jie Wang et. al investigated that in-situ water vaporization improved bitumen production. A water vaporation can transfer effectively the heat from electrical heating to the oil. In electrical process, the enter formation water acts as an electric circuit because the formation water is ionically conductive. When the formation water is heated up to the saturation temperature at the corresponding pressure, it vaporizes into steam. This volume expansion should push more bitumen out of the reservoir and then, the pressure shock generated by gas expansion could be much stronger than the drainage capillary pressure required to displace bitumen off the pore place. K. Visome (1988) used electrical heating to modeling in the field with modified Tetrad. In this case, the electrical heating has done in Sparky formation in the Frog Lake Area and completed for electrical heating in June 1988. The production increased over than 12 m³/day by using the input power during stimulation averaged 15 kW. Bernd Wacker (2011) gave the road map to step by step to build the electromagnetic heating in the field. In this case, he showed how to build the electromagnetic in field and how to make the arrangement in the well of electromagnetic heating. In this paper, we study how to make efficiency of the electrical heating in reservoir. There are many factors which can support to transfer electrical energy to reservoir, i.e. water saturation, water salinity, capacity and conductivity reservoir. On the other hand, the expansion of volume liquid reservoir by heating is not enough for pressure maintenance. Because of that, reservoir pressure will dramatically decrease. To maintain the reservoir uses water injection. If the heat can generate steam of all water injection so the process will be in good condition. The opposite here, the energy of electrical heating is not enough to make the water into steam, so that, the energy from electrical heating will be consumed water very much. To minimize this case, an hybrid of solvent –water injection is used to improve heat go through to crude oil and the solvent will accelerate viscosity reduction. The propose of this study is using of different heat capacity of water and solvent. The heat capacity of water is higher than solvent. The function of solvent is to maintain pressure, while the water is used as media transfer from electrical heating to crude oil. If the injection of water is very high, then the water will highly consume heat. Therefore, the heat in crude oil will decrease and of course this effect is not good for the process. If the solvent is added to water, the heat into the water will decrease and the heat into crude oil will increase. The important idea of this research is to maximize heat into the crude oil. Moreover, if the solvent is very much to be injected so the mobility ratio of crude oil and solvent is very small, so that the sweeps efficiency will decrease. Beside, the goal research is to make optimization of injection rate solvent and water composition.
METHODOLOGY
A novel electrical heating of Athabasca oil sand was analysed by CMG STARS. The model is built with five pattern sport wells. One well in the center is as injection and the other wells are as production. The boundary of model is no-flow and the bottom of reservoir is without water influx. The electrode is posted in all wells including production wells. Furthermore, all reservoir thickness post electrode and the well perforation is all of net reservoir thickness. In this case, the negative electrode is assembled in production well and the positive electrode is posted in the injection well. Hopefully, the heat can be connected from injection well to production wells. The round of production well is about 246 ft and production well to injection well is about 174 ft. The electrical heating uses frequency 60 Mhz and total power in the field is about 175 kWatt and the voltage 220 volt.

RESERVOIR SIMULATION
This model is used to understand propagation of lateral heat, absorb of electrical power in reservoir and recovery factor. The general data for reservoir modeling shows in Table 1. Furthermore bitumen and heavy oil viscosity are shown in figure 1. The calculation of crude oil viscosity at 15 API and 20 API uses Winprop from CMG simulator with PVT basic model and the graphic curvature follows the Athabasca model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Ney Pay, ft</td>
<td>66</td>
</tr>
<tr>
<td>Depth, ft</td>
<td>820</td>
</tr>
<tr>
<td>Permeability, Kh</td>
<td>5000</td>
</tr>
<tr>
<td>Kv/Kh</td>
<td>0.8</td>
</tr>
<tr>
<td>Porosity, %</td>
<td>0.34</td>
</tr>
<tr>
<td>Initial Pressure, Psi</td>
<td>290</td>
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<tr>
<td>Initial Temperature, °F</td>
<td>52</td>
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<tr>
<td>Oil saturation</td>
<td>0.85</td>
</tr>
<tr>
<td>Compressibility (1/psi)</td>
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</tr>
<tr>
<td>Oil</td>
<td>3.15E-06</td>
</tr>
<tr>
<td>Water</td>
<td>4.72E-06</td>
</tr>
<tr>
<td>Rock</td>
<td>3.45E-05</td>
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<tr>
<td>Specific heat (BTU/(lb-°F))</td>
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<tr>
<td>Oil</td>
<td>0.1999</td>
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<tr>
<td>Water</td>
<td>0.9673</td>
</tr>
<tr>
<td>Rock</td>
<td>0.5804</td>
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<tr>
<td>Thermal Conductivity (BTU/ft-day °F)</td>
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<tr>
<td>Oil</td>
<td>2.9217</td>
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<tr>
<td>Water</td>
<td>10.9913</td>
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<tr>
<td>Rock</td>
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<tr>
<td>Overburden</td>
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<td>Bitumen Dencity @ TR, kg/m3</td>
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However, some oil fields have specific correlation to calculate viscosity but it uses general correlation. Figure 2 shows viscosity of solvent. Figure 3 shows relative permeability water-oil.
and figure 4 shows relative permeability oil-gas. Actually, the relative permeability has specific value in each reservoir. In this study, this variable is as espousal reservoir model and it is not sensitive. Reservoir temperature was monitored to know the spreading of electrical power in reservoir and impact of movable oil saturation. Initialization of model got OOIP about 0.21 MMSTB and water 37 MSTB. The assumption of this model was dead oil and excluding gas saturation so as the reservoir model was free gas. The scheme of model is shown in Figure 5.

In the first time, preheating was done on the model about 6 month to reduce bitumen viscosity near bore hole. Effect of this case, the crude oil will be easy to move from reservoir to bore hole. All wells were produced for 6 month to drain oil near bore hole especially well in the center. After that, the center well was used as injection well. The production wells were constrained with Pwf about 50 psi and the production rate maximum was no constraint. The injection pressure was constrained with about 430 psi and the rate of maximum injection was no restraint. The wells produced from 2012 until 2035 for bitumen and heavy oil with density 15 API, while, heavy oil with density 20 API is only until 2025. The oil rate limit of all scenarios was constrained about 5 STB/day.

**Figure 1.**
Viscosity of bitumen and heavy oil *(Modifield from J Wang, 2008)*

**Figure 2.**
Viscosity of Solvent

**Figure 3.**
Relative permeability of water-oil

**Figure 4.**
Relative permeability of gas-liquid
DISCUSSION
Scenario of this study consist of base case, oil density of 15 API, and oil density of 20 API. The base case uses Athabasca filed data and the other case was change of crude oil density. The change of density is to analysis effect of recovery factor. Each scenario uses the same production operation but the solvent water ratio was different.

Base Case
This model is basic of all analysis. Figure 6 shows that the recovery factor will be different with changing of ratio solvent-water. Without solvent, the recovery factor is about 34%. However, if the water injection is added by solvent, the recovery factor will increase. The optimum case has ratio solvent-water about 22% and then, the recovery factor will get about 37%. If the ratio of solvent-water is enhanced, the recovery factor will decrease, for example ratio solvent-water of 24%. The mixing of solvent and water as injection fluid causes the reservoir can maintain pressure and the heat from electrical minimum loss. Furthermore, if the ratio solvent-water is high, the water viscosity will be down and the mobility water will increase. In other, this process could optimize ratio solvent-water.

On the other hand, if the reservoir did not do the injection, the recovery factor would be only 2.5%. This case was caused by decreasing of the pressure dramatically. Another case, if the reservoir was injected by water, the pressure would be maintained.

The electrical power of all scenarios was not full in 175 kW, especially before 2026. After 2026, the electrical power has full value (Figure 7). The different condition of this case is reflected in Figure 8 and Figure 9. In 2025, the reservoir was not fully connected by water injection. After 2026, reservoir was fully connected by water injection. The minimum water saturation causing fully connected was about 35%.
The oil production rate was very small after preheating. This condition is caused by effect of not full power in electrical heating. As can be seen in Figure 10, the electrical power has correlation
with production rate. In 2012 until 2025, the electrical heating is not maximum so the rate production is the same. In 2026, the pick production is accured in the wells, but in 2027, the production rate will decline. This case, the water injection has arrived in production wells. After that, the oil saturation will gradually decrease especially in line of injection well to production wells (Figure 11).

In the first time, the temperature of reservoir is about 51 °F. By the time, the temperature will gradually rise due to electrical heating. At the end of electrical heating process, the part of reservoir temperature is about 150 °F (Figure 12). In this case, the electrical heating only generates hot water instead of steam. In the same case, the cumulative electrical heating shows in Figure 13.

![Figure 12](image1.png)

**Figure 12**
Temperature Distribution in 2035

![Figure 13](image2.png)

**Figure 13.** Cummulative electrical energy distribution in the end production (2035)

### Oil Density 15 and 20 API

This scenario uses oil density 15 and 20 API. The research aims to know the effect of the density change. As can been seen, the bitumen recovery got about 37% after producing about 23 years. After the density was changed with 15 API, the recovery factor increased until more than 50%. If the solvent-water was injected together, the recovery factor increased to about 2% compared without solvent. This case has difference about 2% with bitumen Athabasca. The condition of oil density of 15 API was better than bitumen. Furthermore, if the recovery factor of 15 API densities was compared with density of 20 API, the value was very different. The recovery got about 68% in density oil of 20 API and only needed about 13 years (Figure 14). But after the solvent was added to water injection, the effect of solvent was not significant. So, if the oil density decreased, the effect of solvent would decrease. Thus, the solvent could not improve oil recovery if the oil density was more than 15 API.

Effect of preheating, in the oil density of 15 and 20 API was very different. In the density oil of 15 API, oil rate after preheating was about 35 STB/day, while for density oil of 20 API, the oil rate was about 90 STB/day The effect of water injection was very significant for oil density of 20 API. After production in preheating process, the production rate dropped almost zero. However, the production rate would increase after water injection (Figure 15).
Table 2 shows the summary of all good scenario. The hybrid solvent-water will effective in bitumen and the density less than 15 API. Otherwise, the density more than 20 API will not effective again.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Production time</th>
<th>Oil Type</th>
<th>Recovery factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base case (without injection)</td>
<td>23 years</td>
<td>Bitumen</td>
<td>2.5 %</td>
</tr>
<tr>
<td>2</td>
<td>Water Injection</td>
<td>23 years</td>
<td>Bitumen</td>
<td>34 %</td>
</tr>
<tr>
<td>3</td>
<td>Water injection (solvent –water : 22%)</td>
<td>23 years</td>
<td>Bitumen</td>
<td>37 %</td>
</tr>
<tr>
<td>4</td>
<td>Water Injection</td>
<td>23 years</td>
<td>15 API</td>
<td>51 %</td>
</tr>
<tr>
<td>5</td>
<td>Water injection (solvent –water : 22%)</td>
<td>23 years</td>
<td>15 API</td>
<td>53 %</td>
</tr>
<tr>
<td>6</td>
<td>Water Injection</td>
<td>13 years</td>
<td>20 API</td>
<td>68 %</td>
</tr>
</tbody>
</table>

CONCLUSIONS
Base on the previous description and discussion can be summarized as follow:

1. A novel electrical heating method is one of alternative to produce bitumen and heavy oil. To improve oil recovery, the pressure should be maintained with water. Adding of solvent in the water injection will improve oil recovery.

2. The bitumen injected by water has recovery factor about 34%. If the solvent is added to the water by composition about 22%, the recovery factor will increase to 37% for 23 years.

3. For the sensitivity of density in the model, it shows that the density oil of 15 API has recovery factor about 51% and, if the solvent-water is added by 22 %, the recovery factor will improve about 53% for 23 years. The condition is different with density oil of 20 API. For 13 years, the oil density of 20 API has recovery factor about 68 %.

4. A hybrid solvent-water injection will be effective for the bitumen. If the density is more than 15 API, the solvent-water will not effective again.

5. A novel electrical heating method will be effective and strongly recommended in the oil density around 20 API.
NOMENCLATURE

API = American Petroleum Institute
Pwf = Pressure well flow
PVT = Pressure volume temperature
So = oil saturation
Sw = water saturation
kW = kilo watt
μ = Viscosity, cp
T = Temperature, ºF

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