

COMPARISON FOR OIL RECOVERY BETWEEN WATER AND POLYMER FLOODING IN THE U-THONG OIL FIELD

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Abstract

The objective of this research is to compare water and polymer flooding case studies by using a reservoir simulation to simulate the improvement of oil recovery in the reservoir of the U-Thong oil field and to study the economics of both methods to find the best case scenario. The physical properties of the reservoir rock and fluids, porosity, permeability, and reservoir pressure were collected from a literature review and theoretical assumptions. The reserve size of the reservoir is around 6.48 million barrels injected with a direct drive pattern (2 production wells and 2 injection wells) in the 1st year. Results of this research revealed that polymer flooding is the best method, as the summary of the oil recovery factor and net present value result is 55.03% and 35.53 MMUS\$, respectively (more than water flooding at 5.57% and 2.52 MMUS\$, respectively).

Keywords: U-Thong oil field, water flooding, polymer flooding, reservoir simulation

Introduction

These research studies focus on the U-Thong oil field in Thailand. The reservoir has low pressure, and production requires an artificial lift system using a sucker rod pump to pump crude oil to the surface. This research aims to improve oil recovery by reducing the residual oil left in the reservoir. The 2 methods used in this research are the water flooding and polymer flooding techniques. The Eclipse simulation software will be used to design the reservoir pattern and to find the efficiency for comparing the economics.

U-Thong Oil Field

The U-Thong oil field that is a part of the Suphan

Buri Basin is around 80 km north-west of Bangkok, covering an area of approximately 5.06 km² in Suan Taeng subdistrict, and Mueang and U-Thong districts, Suphan Buri province. In 1993, PTT Exploration and Production Public Company Limited revised the stratigraphy of the oil field into 5 units, namely A, B, C, D, and E units starting from the bottom up to top, as illustrated. Detailed descriptions of each unit are discussed in Tongpenyai *et al.* (2000). The main reservoir interval of the U-Thong oil field is Unit D. There are 2 main production zones: the Upper zone (layers KR1-1 to KR2-5), and the Lower zone (layers KR2-6 to KR2-8). The

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recovery factor of the Upper zone is 5 % and that of the Lower zone is 30 %. This difference in the recovery factors is because the Upper zone is believed to have a depletion drive mechanism and the Lower zone is believed to have a water drive mechanism (Tuan, 2005). This research is applied from the Lower zone only. According to Htoo (2009), from a test of 4 wells, the effective porosity of the reservoir units is at 22% in KR1-1 and decreases with the burial depth to an average value of 12% in unit KR2-8B, using an equation from a porosity-permeability scatter program to generate the geo-statistical permeability distribution. This equation used is $\text{Log}(k) = 0.2023 \times \phi - 2.3475$ (Rattanapranudej, 2004). The oil gravity is 33°API.

Water Flooding

This method uses water injected into the reservoir formation to displace residual oil. The water from the injection wells physically sweeps the displaced oil to adjacent production wells. Potential problems associated with water flooding techniques include inefficient recovery due to variable permeability or similar conditions affecting fluid transport within the reservoir, and early water breakthrough that may cause production and surface processing problems (Schlumberger Ltd., 2009).

Polymer Flooding

Polymer flooding is a type of chemical flooding to control drive-water mobility and fluid flow

patterns in reservoirs. Long, chainlike, high-weight polymer molecules have 3 important oil recovery properties. They increase water viscosity, decrease effective rock permeability, and are able to change their viscosity with the flow rate. Small amounts of water-dissolved polymer increase the viscosity of the water. This higher viscosity slows the progress of the water flow through a reservoir and makes it less likely to bypass the oil in low permeability rock (Gerding, 1986).

The polymers can be commercially categorized into 2 types, polyacrylamides (PAM) and polysaccharides (biopolymers or xanthan gum). Polysaccharides are less expensive than PAM but they have a good salt-resistance and a better heating resistance than PAM. A xanthan gum polymer concentration of 600 ppm is used in this research. The reservoir has a high temperature and this polymer can increase the water viscosity but the mobility ratio between the polymer solution and the oil will be decreased. A study of enhanced oil recovery by polymer flooding for an oil field in the Phisanulok basin (Kanarak, 2008) showed that the reservoir model, named A05, is nearby this research. The polymer concentration of 600 ppm is the best for this case and the development for each of the reserved sizes of the reservoir. The recovery efficiency and economic evaluations are more favorable than the other concentrations.

Table 1. Summary of reservoir and fluid properties

Parameters	Properties
Net-to-gross ratio	0.18 - 1.00
Porosity	12 - 15 %
Permeability	89.68 - 362.74 md
Rock type	Consolidated sandstone
Oil gravity	33°API
Gas gravity	0.74
Bubble point pressure	300 psi
Referenced pressure	1800 psi
Water-oil contact depth	3875 ft
Datum depth	3850 ft

Reservoir Simulation

Reservoir simulation is a technique in which a computer-based mathematical representation of the reservoir is constructed and then used to predict its dynamic behavior. Simulation is the only way to describe quantitatively the flow of multi-phases in a heterogeneous reservoir having a production schedule determined not only by the properties of the reservoir, but also by market demand, investment strategy, and government regulations. The reservoir is divided into a number of grid blocks. The reservoir

rock properties (porosity, saturation, and permeability) and the fluid properties (viscosity and pressure-volume-temperature data) are applied for each grid block (Noianusontigul, 2008). This research used black-oil reservoir simulation with Eclipse Office E100 to simulate water and polymer flooding which was based on the available data of the U-Thong oil field and some data assumptions. The reservoir simulation model has 3750 cells ($25 \times 25 \times 6$ grid blocks) with 6 layers. The production and injection wells are located with direct line drive. The summary

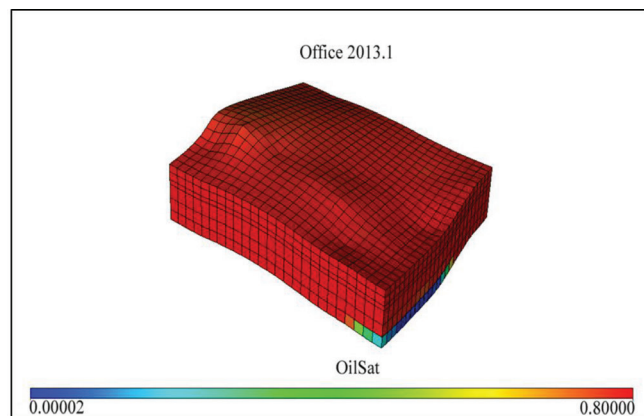


Figure 1. Reservoir structure model

Table 2. Case studies

Case study	Type of injection	Years of injection	Production rate (bbl/d)	Injection rate (bbl/d)
1	-	no	600	0
2	Water	1 st – 20 th	600	500
3	Fresh water	1 st	600	500
	Polymer	2 nd – 20 th		

Table 3. Summary of reservoir simulation results

Case study	Type of fluid injection	Cumulative oil production(bbl)	RF (%)
1	No injection	1687469.4	26.05
2	Water	3192379.3	49.28
3	Polymer	3565103.5	55.03

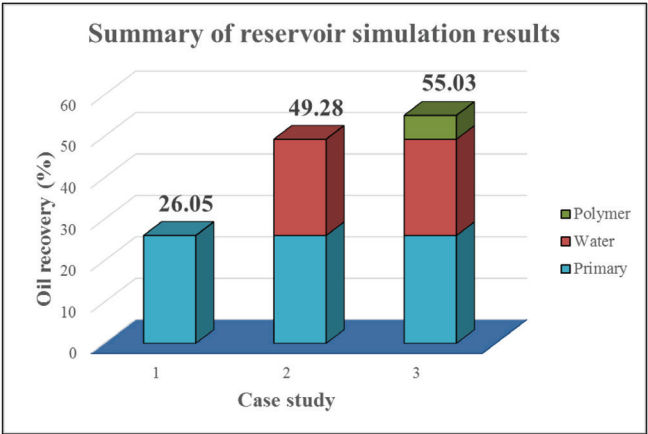


Figure 2. Summary of reservoir simulation results

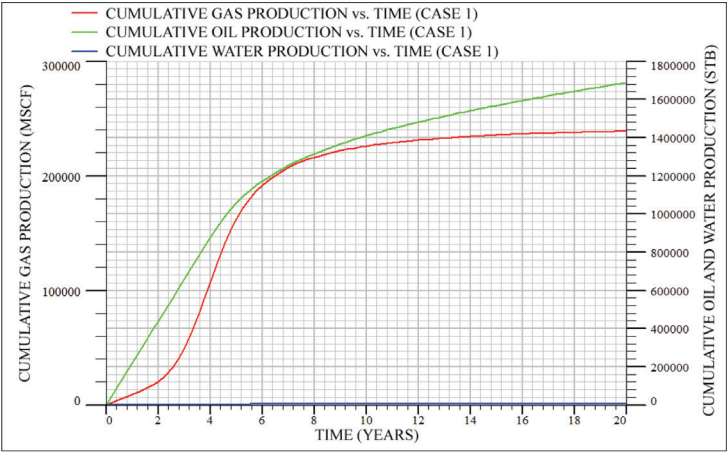


Figure 3. Cumulative production total vs time (case 1)

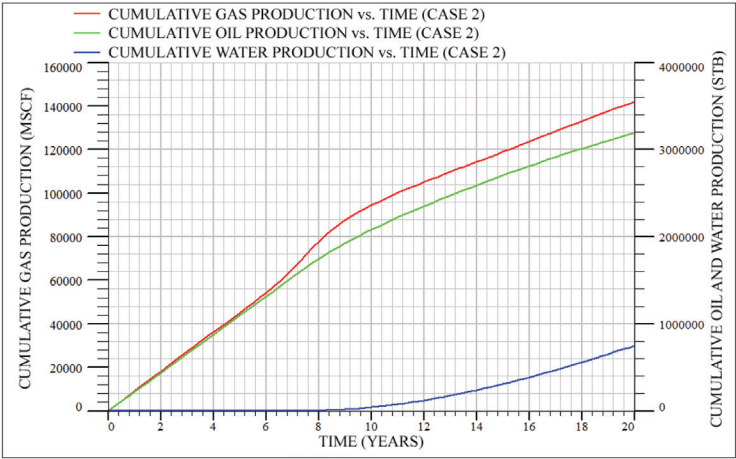


Figure 4. Cumulative production total vs time (case 2)

of the reservoir and fluid properties is shown in Table 1. The reservoir size is 6.478 million barrels (MMbbl) with the monocline structure style shown in Figure 1. A direct line drive pattern (2 production wells and 2 injection wells) is used to compare the results of the production with the primary production (natural flow), secondary production (water injection), and tertiary production (polymer injection). Water

and polymer injection in the 1st year of constant production is at the rate of 600 bbl/day and the constant injection rate is at 500 bbl/day. The case studies are shown in Table 2.

Reservoir Simulation Results

The recovery factor of the primary production in this reservoir model is low. The effects of the water and polymer flooding methods are

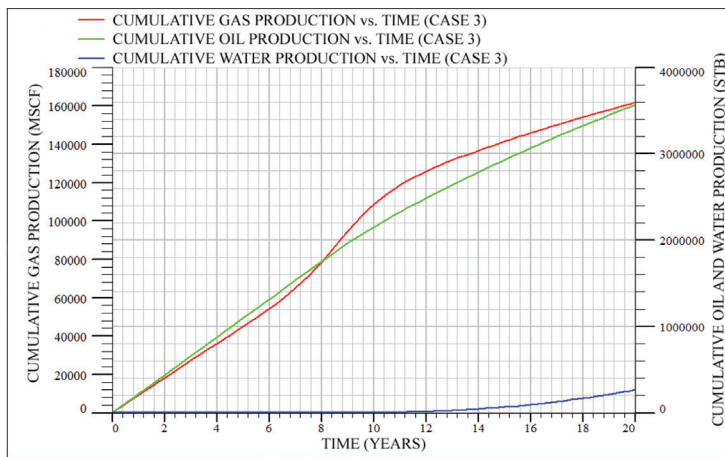


Figure 5. Cumulative production total vs time (case 3)

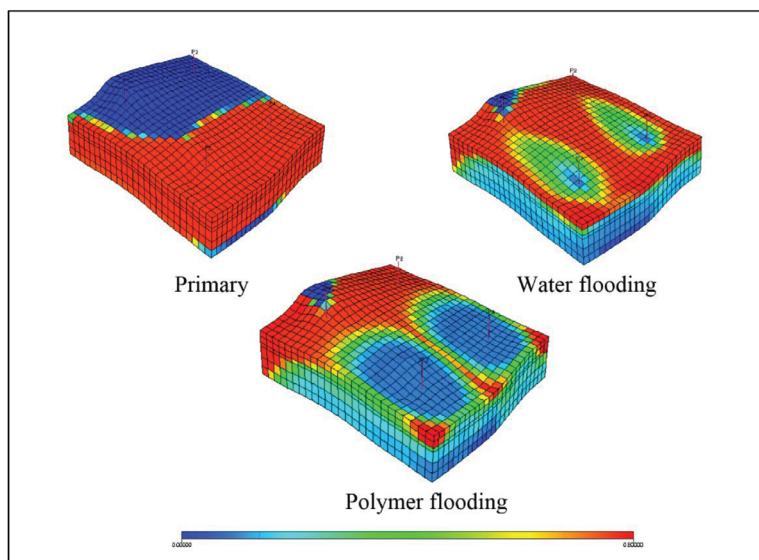


Figure 6. Oil saturation after 20 years production of all case studies

increased reservoir pressure and oil recovery. The advantages of the polymer solution are improvements in the swept coefficient and volumetric sweep efficiency, and a decrease in the mobility ratio. The results show that in the case of polymer flooding there is high performance for oil recovery efficiency when compared with natural flow and water flooding. Natural flow (no water or polymer injection) can produce 26.05% of oil in place. The oil recovery with water and polymer flooding increased to 49.28% and 55.03%, respectively. A summary of the reservoir simulation results is shown in Figures 2, 3, 4, and 5 and in Table 3. The oil saturation after 20 years production for all the case studies is shown in Figure 6.

Economic Evaluation

Economic evaluation is the final step in this research, and the objective is to determine the economic parameters that are used to analyze the project investment possibility including the net present value (NPV), profit investment ratio (PIR), and internal rate of return (IRR). A comparison was made of all the case studies to find the best method for the U-Thong oil field. The economic evaluation of this research is based on a constant oil price rate through the project lifetime of 95 \$/bbl and a 7.5% discounted rate. The economic evaluation parameters used in this research are shown in Table 4.

The best operational case for this research is to use polymer flooding for which the IRR after tax and the 7.5% discount is 38.49%, the PIR is 1.233, and the best NPV is 36.94 MMUS\$. The economic results summaries of all the case studies are shown in Tables 5, 6, 7, and 8 and the summary of the NPV results is shown in Figure 7.

Conclusions

The reservoir simulation results indicated that the polymer flooding technique can increase oil recovery efficiency compared with the natural flow and water flooding techniques for the U-Thong oil field. There was an increase in the oil recovery efficiency over the natural flow and water flooding techniques to 28.98% and an increase to 5.75% of oil in place.

History matching should be compared with the real field and the reservoir simulation because it is a necessary step for more accurate results, but the production rates could not be accessed in the oil field for this study. The more data that can be obtained on the reservoir properties the more accurate the results are. For future study, the locations of the production and injection wells can be increased to five, seven, and nine sites to find the oil recovery efficiency and economic values for the U-Thong oil field. The reliability of the simulation results depends on the accuracy of the input data of the simulators.

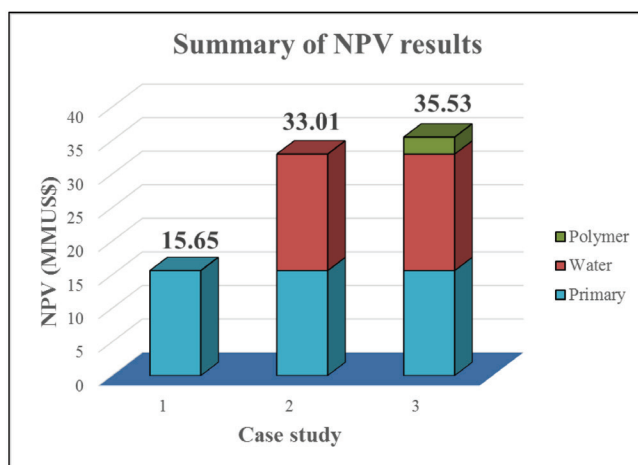


Figure 7. Summary of NPV results

Table 4. Economic evaluation parameters

Expenditure Cost Details	All case studies
Dubai oil price (US\$/bbl)	95
Income tax (%)	50
Inflation rate (%)	2
Real discount rate (%)	7.5
Sliding scale royalty (%)	
Production level (bbl/day)	
0 - 2,000	5
2,000 - 5,000	6.25
5,000 - 10,000	10
10,000 - 20,000	12.5
> 20,000	15
Concession (MMUS\$)	0.5
Geological and geophysical survey (MMUS\$)	2
Production facility (MMUS\$)	20
Drilling and completion production well (MMUS\$/well)	2
Drilling and completion injection well (MMUS\$/well)	1.5
Drilling exploration & appraisal well (MMUS\$)	1
Facility costs of water injection well (US\$/well)	63500
Facility costs of polymer injection well (US\$/well)	65000
Maintenance costs of water injection well (US\$/year)	42500
Maintenance costs of polymer injection well (US\$/year)	42500
Cost of polymer including transportation (US\$/kg)	7
Abandonment cost (US\$)	12500
Operating costs of production well (US\$/bbl)	20
Operating costs of water injection (US\$/bbl)	0.5
Operational costs of polymer injection (US\$/bbl per incremental barrel of oil)	1

*MMUS\$ = Million US Dollars

Table 5. Economic results summary of all case studies

Case study	IRR (7.5% Discount) (%)	PIR (7.5% Discount) (Fraction)	NPV (7.5% Discount) (MMUS\$)
1	25.62	0.497	15.65
2	35.39	1.078	33.01
3	35.33	1.078	35.53

*MMUS\$ = Million US Dollar

Table 6. Cash flow summary of case 1. Recovery factor = 26.05 %

Year	Cash flow summary							Discount cash flow (NPV@7.5%)
	Oil production total	Gross revenue	CAPEX	OPEX	Government take		Annual cash flow	
					Royalty	Inc. tax		
(bbl/year)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	
1	0.000	0.000	0.500	0.000	0.000	0.000	-0.500	-0.465
2	0.000	0.000	2.000	0.000	0.000	0.000	-2.000	-1.731
3	0.000	0.000	1.000	0.000	0.000	0.000	-1.000	-0.805
4	0.000	0.000	28.000	0.000	0.000	0.000	-10.720	-8.027
5	219000	20.805	0.000	4.741	1.040	0.000	10.704	7.456
6	219000	20.805	0.000	4.836	1.040	5.304	5.304	3.437
7	219600	20.862	0.000	4.946	1.043	5.276	5.276	3.180
8	208236	19.782	0.000	4.784	0.989	4.845	4.845	2.716
9	150842	14.330	0.000	3.535	0.716	5.039	5.039	2.628
10	103573	9.839	0.000	2.476	0.492	3.436	3.436	1.667
11	77728	7.384	0.000	1.895	0.369	2.560	2.560	1.155
12	62001	5.890	0.000	1.542	0.295	2.027	2.027	0.851
13	52582	4.995	0.000	1.334	0.250	1.706	1.706	0.666
14	45833	4.354	0.000	1.186	0.218	1.475	1.475	0.536
15	40848	3.881	0.000	1.078	0.194	1.304	1.304	0.441
16	36739	3.490	0.000	0.989	0.175	1.163	1.163	0.366
17	33380	3.171	0.000	0.916	0.159	1.048	1.048	0.307
18	30759	2.922	0.000	0.861	0.146	0.957	0.957	0.260
19	28918	2.747	0.000	0.826	0.137	0.892	0.892	0.226
20	27343	2.598	0.000	0.797	0.130	0.836	0.836	0.197
21	26103	2.480	0.000	0.776	0.124	0.790	0.790	0.173
22	25068	2.381	0.000	0.760	0.119	0.751	0.751	0.153
23	24228	2.302	0.000	0.749	0.115	0.719	0.719	0.136
24	23619	2.244	0.000	0.745	0.112	0.693	0.693	0.122
Total	1655401	157.263	31.500	39.771	7.863	40.823	37.306	15.646
						IRR	35.04%	25.62%
						PIR	1.184	0.497

Table 7. Cash flow summary of case 2. Recovery factor = 49.28%

Year	Cash flow summary							Discount cash flow (NPV@7.5%)
	Oil production total	Gross revenue	CAPEX	OPEX	Government take		Annual cash flow	
					Royalty	Inc. tax		
(bbl/year)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	
1	0.000	0.000	0.500	0.000	0.000	0.000	-0.500	-0.465
2	0.000	0.000	2.000	0.000	0.000	0.000	-2.000	-1.731
3	0.000	0.000	1.000	0.000	0.000	0.000	-1.000	-0.805
4	0.000	0.000	24.131	0.000	0.000	0.000	-7.386	-5.531
5	219000	20.805	0.000	4.886	1.040	0.000	10.693	7.448
6	219000	20.805	0.000	4.984	1.040	5.298	5.298	3.433
7	219600	20.862	0.000	5.097	1.043	5.268	5.268	3.175
8	219000	20.805	0.000	5.185	1.040	5.197	5.197	2.914
9	219000	20.805	0.000	5.289	1.040	7.238	7.238	3.775
10	219000	20.805	0.000	5.394	1.040	7.185	7.185	3.486
11	219600	20.862	0.000	5.517	1.043	7.151	7.151	3.227
12	211584	20.101	0.000	5.428	1.005	6.834	6.834	2.869
13	178490	16.957	0.000	4.697	0.848	5.706	5.706	2.228
14	155135	14.738	0.000	4.187	0.737	4.907	4.907	1.783
15	140717	13.368	0.000	3.890	0.668	4.405	4.405	1.489
16	130390	12.387	0.000	3.690	0.619	4.039	4.039	1.270
17	123336	11.717	0.000	3.570	0.586	3.781	3.781	1.106
18	117558	11.168	0.000	3.479	0.558	3.565	3.565	0.970
19	112627	10.700	0.000	3.409	0.535	3.378	3.378	0.855
20	107476	10.210	0.000	3.326	0.511	3.187	3.187	0.750
21	102533	9.741	0.000	3.246	0.487	3.004	3.004	0.658
22	97566	9.269	0.000	3.160	0.463	2.823	2.823	0.575
23	92636	8.800	0.000	3.071	0.440	2.645	2.645	0.501
24	88132	8.373	0.000	2.991	0.419	2.482	2.482	0.437
Total	3192379	303.276	27.631	84.495	15.164	88.090	87.897	34.418
IRR						48.99%	38.59%	
PIR						3.181	1.246	

Table 8. Cash flow summary of case 3. Recovery factor = 55.03%

Year	Cash flow summary							Discount cash flow (NPV@7.5%)
	Oil production total	Gross revenue	CAPEX	OPEX	Government take		Annual cash flow	
					Royalty	Inc. tax		
(bbl/year)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	(MMUS\$)	
1	0.000	0.000	0.500	0.000	0.000	0.000	-0.500	-0.465
2	0.000	0.000	2.000	0.000	0.000	0.000	-2.000	-1.731
3	0.000	0.000	1.000	0.000	0.000	0.000	-1.000	-0.805
4	0.000	0.000	24.131	0.000	0.000	0.000	-7.386	-5.531
5	219000	20.805	0.000	4.886	1.040	0.000	10.693	7.448
6	219000	20.805	0.122	5.052	1.040	5.202	5.202	3.371
7	219000	20.805	0.122	5.153	1.040	5.152	5.152	3.105
8	219600	20.862	0.122	5.270	1.043	5.120	5.120	2.871
9	219000	20.805	0.122	5.361	1.040	7.141	7.141	3.725
10	219000	20.805	0.122	5.469	1.040	7.087	7.087	3.439
11	219000	20.805	0.122	5.578	1.040	7.032	7.032	3.174
12	219600	20.862	0.122	5.704	1.043	6.996	6.996	2.937
13	210511	19.999	0.122	5.588	1.000	6.644	6.644	2.595
14	188645	17.921	0.122	5.134	0.896	5.885	5.885	2.138
15	172247	16.363	0.122	4.804	0.818	5.310	5.310	1.794
16	162408	15.429	0.122	4.635	0.771	4.950	4.950	1.556
17	153644	14.596	0.122	4.487	0.730	4.629	4.629	1.354
18	147324	13.996	0.122	4.400	0.700	4.387	4.387	1.193
19	142070	13.497	0.122	4.338	0.675	4.181	4.181	1.058
20	137047	13.019	0.122	4.278	0.651	3.984	3.984	0.938
21	131362	12.479	0.122	4.195	0.624	3.769	3.769	0.825
22	126557	12.023	0.122	4.133	0.601	3.583	3.583	0.730
23	122181	11.607	0.122	4.081	0.580	3.412	3.412	0.647
24	117909	11.201	0.122	4.028	0.560	3.246	3.246	0.572
Total	3565104	338.685	29.948	96.576	16.934	97.710	97.516	36.939
						IRR	48.88%	38.49%
						PIR	3.256	1.233

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