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Extending Shale Gas Well Life with Low Grade Geothermal Power — Haynesville Case

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Keywords

Enhanced Geothermal System, heat extraction, Haynesville Shale, Hot Dry Rock, multistage fracturing, horizontal well, shale gas, Stimulated Reservoir Volume

ABSTRACT

The hydraulic fracture network of a shale gas well, after its production rate has dropped below the economic limit, can be used for low grade geothermal heat extraction. Conceptually, the Stimulated Reservoir Volume (SRV) for the shale gas well consists of multiple parallel transverse fractures created along one horizontal well. The idea investigated is to connect the created hydraulic fractures with horizontal wells. For a single well SRV, horizontal wells could be drilled at the fracture tips. However, for multiple SRVs, if the tips of fractures created from adjacent parallel horizontal wells are sufficiently connected, it may be possible to use existing horizontal wells.

Cold water is to be pumped into one horizontal well connected to the network of parallel fractures. The water is heated by contact with the hot rock, and then recovered through a second horizontal well connected to the same network of parallel fractures and parallel to the first horizontal well. The basis of this concept is to use the already created SRV for heat transfer purposes. Considering the low thermal conductivity of shale, we show simulations indicating that typical well completions in the Haynesville Shale provide sufficient heat transfer area to heat injected water to temperatures suitable for electric power generation. After flowing through the SRV fracture network, produced hot water is passed through a heat exchanger, transferring heat to a working fluid in the power plant. The vaporizing working fluid is expanded across a turbine to drive a generator and produce electricity. The hot water, upon exiting the heat exchanger, is injected back into the reservoir to collect additional heat, thus forming a closed loop cycle.

Introduction

Extraction of heat from Hot Dry Rock (HDR) is a relatively new concept and is gaining prominence among other alternate energy resources due to its abnormally high energy generating potential and its long lasting nature. Unlike hydrothermal reservoirs, which are relatively rare and occur less frequently, HDR is present everywhere beneath the sub surface (Edwards 1982). Most of the heat in HDR exists in areas with little or no permeability to flow of fluids (Abé et al. 1999). Enhanced Geothermal System (EGS) refers to the technique of creating artificial fracture networks in order to provide flow path through the rock sufficient to mine the stored heat energy via heat conduction and convection through the rock to the fluid. EGS can be referred to as an "engineered" system because the operator has full control over the volume of the stimulated region.

The Future of Geothermal Energy, a project funded by the Department of Energy (DOE) estimated that the United States EGS energy generating potential could reach a capacity of 100,000 MWe by the year 2050 (Bodvarsson and Tsang 1980). The value is roughly equal to one-third of the power from all coal-generating power plants in US. The United States Geological Survey (USGS) estimates 500,000 MWe as the total EGS potential, which is nearly half of the total power generating capacity of all energy sources.

EGS offers benefits towards increased power output, siting and sizing flexibility, extended resource life and environmental advantages. The economic viability of an HDR energy resource development using EGS techniques mainly depends on the rate of thermal drawdown. In a practical standpoint, an HDR SRV would be sized and operated depending on the capacity of the geothermal power plant at the surface. A small scale commercial geothermal power plant of 5 MW electricity generating capacity operating on water at a temperature of 300°F requires a flow rate at least as high as 150 kg/s. Large HDR systems are required to meet these flow rate requirements. The size of an HDR system can be increased by developing multiple SRVs to serve a single power plant.

Robinson (1971) suggests drilling two parallel boreholes adjacent to each other with the second borehole intersecting a series of parallel vertical fractures created as a result of fracturing the formation in the first borehole. The technique not only reduces the cost of drilling additional boreholes but also the system designed in such a way can supply energy to a power plant of any desired size. Because of the low thermal conductivity of the rocks, a very large surface area is necessary for heat transfer. The method of Multistage Transverse Fracturing of Horizontal Wells (MTFHW) can play a significant role in achieving this large surface area. Massive multistage hydraulic fracture treatments are necessary to contact as much rock as possible with a network of fractures that establish adequate connection to the well (Fisher et al. 2004).

Figure 1 shows a diagram representing the approximate configuration of Haynesville Shale gas wells. The wells are about 4000 ft long and spaced 600 ft apart. Created fracture half

lengths are about 300 ft, and the spacing between fractures is about 50 ft. Typically there are 5 to 6 fractures per stage and 10 to 12 stages per well. In Figure 1, solid lines represent fractures created from horizontal wells represented by dotted lines. Two such horizontal wells that are in hydraulic connection with each other are used for circulating the fluid. Cold fluid (water in our case) is injected into



Figure 1. Idealization of Haynesville Shale gas well array.

one horizontal well and recovered from second horizontal well. MTFHW enables creation of a SRV. The major driving force for





Figure 3. Planar view of the SRV for one fracture stage and for one single fracture.

the success of this project is the use of already existing wells for injection and production purposes. It is essential to obtain good connectivity between the wells through the fracture network. Fluid injection may itself be sufficient to achieve the required connectivity. While we do not provide any specific basis for the above statements, we note that operators offer frequent anecdotal evidence about inter-well connectivity.

Figure 2 shows an idealized model for the shale gas SRV associated with a single hydraulic fracture stage. The length of the rectangle is equal to horizontal well length and its width is equal to twice the half length of the created hydraulic fractures.

Figure 3 shows a picture of an SRV for a single fracture unit. The temperature interference between two fractures and two adjacent wells result in the formation of virtual no heat flow boundaries mid-way between the fractures.

In this paper, we base our discussions on analytical and numerical models developed for extracting heat from a single fracture unit (building block of the SRV). The analytical and numerical models are applied to SRV of a typical MTFHW shale gas well in Haynesville Shale as shown in Figure 2. The results are analyzed in order to understand the dependence of power output on injection/ production constraints and SRV dimensions. A binary cycle power plant designed with Aspen HYSYS program is used to determine the power output. The paper concludes by presenting the economics of the project, conclusions, recommendations and future work.

Case Study

Haynesville Shale Geology

The Haynesville Shale is a black organic-rich shale of Upper Jurassic age located in Northwest Louisiana and Northeast Texas,



Figure 4. Haynesville Shale extending over Texas and Louisiana.

as shown in Figure 4. It extends over an area of 5.8 million acres. It is overlain by Bossier Shale and underlain by the Cotton Valley limestone in Texas and the Smackover carbonate formation in Louisiana. The gross thickness varies from 150-350 ft. Porosity varies from 5-12% and the shale exhibits low water saturation values ranging between 25-35%. Average Total Organic Content (TOC) of the shale is less than 4% indicating high thermal maturity (Wang and Liu 2011). Based on core measurements, Pope et al. (2010) estimated the matrix permeability to range between 5-800 nano-Darcys (nD).

The Haynesville Shale is different from other shale plays because it occurs at a relatively greater depth (11000-14500 ft), is over-pressured (0.7-0.9 psi/ft) and exhibits formation temperatures above 300°F (Thompson et al. 2010). The total technically recoverable gas content of the Haynesville Shale is estimated to be 251 TCF with 80% existing as free gas and the remaining 20% adsorbed on organic surfaces (Fisher et al. 2004).

Analytical Model Implementation

We used the analytical model developed by Gringarten et al. (1975) for studying heat transfer in a series of parallel transverse fracture network. The fractures are assumed to be separated by impermeable blocks having homogeneous and isotropic properties. Gringarten et al. (1975) reports two important conclusions from his work. Dividing the flow rate among different identical fractures results in a reduced flow rate per fracture and hence decreases the rate of drop in water outlet temperature. Reducing the fracture spacing will result in faster temperature drop, but the amount of energy recovered from the rock will be higher.

The thermal front propagation for the case of cold water injection into a horizontal fracture was studied by Bödvarsson and Tsang (1982). Rapid thermal front propagation in the fracture is observed at initial stage of injection with little or no heat transfer taking place into the matrix. Rate of heat transfer into the matrix increases and that in the fracture decreases with time until both the rates become equal. This is also the time when the thermal front in the matrix reaches the no heat flow boundaries. From this point, a uniform energy sweeping mechanism will exist in the SRV. The same phenomena can be observed in transverse fractures of a MTFHW, given the gravity and the buoyancy effects are neglected.

Figure 5 shows the geometry of our analytical model for a single fracture unit. A rectilinear coordinate system is set with x-axis perpendicular to the fractures and the y-axis passing midway between the matrix blocks. The plane of the fracture lies along the



Figure 5. Analytical model for a single fracture unit.

z-axis. Using the symmetry element, only one fracture is modeled. The width of the fracture is denoted by '2b' and the insulated heat flow boundaries are assumed to be located at a distance of ' x_e ' in either direction, where ' $2x_e$ ' is the fracture spacing. The fractures are separated by impermeable blocks of homogeneous and isotropic properties.

Cold water at a temperature ' T_{wi} ' is injected at y=0 into the fracture. The initial rock temperature is ' T_{ri} ' and its thermal conductivity ' k_r ' is assumed to be constant. Mass and volumetric flow rate of the injected water are assumed to be constant. Product of the density (ρ) and heat capacity (C) for both rock and water is assumed to be constant. We assume that the heat transfer takes place only through conduction in the horizontal direction parallel to the x-axis and through convection along the y-axis in the fracture. The water temperature is assumed to be uniform in any cross-section limited to the width of the fracture and is equal to the temperature of the formation at x=b for all times. The geothermal gradient is neglected in this model. Differential equations governing the heat transfer problem are provided below.

$$b\rho_{w}c_{w}\left[\frac{\partial T_{w}(y,t)}{\partial t} + v\frac{\partial T_{w}(y,t)}{\partial y}\right]$$
$$= k_{r}\frac{\partial T_{r}(x,y,t)}{\partial x}(at \ x = b)$$
(1)

$$\frac{\partial^2 T_r(x, y, t)}{\partial x^2} = \frac{\rho_r c_r}{k_r} \frac{\partial T_r(x, y, t)}{\partial t}$$
(2)

where 'v' is the velocity, ' ρ_w ', ' c_w ', ' ρ_r ' and ' c_r ' are the density and specific heat of water and rock respectively.

The rock and the water temperature satisfy the following boundary conditions-

$$T_{r}(x, y, t) = T_{w}(y, t) = T_{ri}, \quad t < \frac{y}{v}$$
 (3)

$$T_r(x,0,t) = T_w(0,t) = T_{ri}, t < 0$$
 (4)

$$T_r(x,0,t) = T_w(0,t) = T_{wi}, \quad t \ge 0$$
 (5)

$$T_{w}(y,t) = T_{r}(b,y,t), \quad \forall y,t$$
(6)

$$\frac{\partial T_r(x, y, t)}{\partial x} (at \ x = x_e) = 0$$
⁽⁷⁾

The solution for the water outlet temperature in Laplace space is given by Equation (8).

$$T_{wD}(y_D, s) = \frac{1}{s} Exp\left[-y_D s^{\frac{1}{2}} \tanh\left(\frac{q\rho_w c_w x_e}{2k_r y_f}\right) s^{\frac{1}{2}}\right]$$
(8)

where ' y_f ' is the fracture length, 'q' is the injection rate per unit fracture per unit fracture height and 's' is the Laplace transform variable.. The dimensionless variables are declared according to Equations (9) to (12). Equation (8) is numerically inverted using the Gaver-Wynn-Rho (GWR) algorithm written in Mathematica. The algorithm generates water outlet temperature as a function of time. Table 1 gives the details of inputs used for the analytical model.

$$y_{\rm D} = \frac{y}{y_{\rm f}} \tag{9}$$

$$x_{\rm D} = \frac{x}{b} \tag{10}$$

$$t_{\rm D} = \frac{\rho_{\rm w}^2 c_{\rm w}^2 q^2 t}{4k_{\rm r} \rho_{\rm r} c_{\rm r} {y_{\rm f}}^2}$$
(11)

$$T_{rD}(x_{D}, y_{D}, t_{D}) = \frac{T_{ri} - T_{r}(x, y, t)}{T_{ri} - T_{wi}}$$
(12)

Table 1. Inputs for the analytical model.

	T _{ri} , °F	Initial rock temperature	350
	k _r , Btu/ft-day-°F	Rock thermal conductivity	24.36
	ρ_r , lb/ft ³	Rock density	144
	c _r , Btu/lb-°F	Rock specific heat	0.391
T _{wi} , °F nof		Injection water temperature	86
		No. of transverse fractures	80

Discussion of Results

Since the rock matrix is impermeable, injection and production rates are equal. From sensitivity studies at different per fracture flow rates, we observe that the water outlet temperature drop is slower for smaller flow rates and faster for larger flow rates. Cold thermal front breakthrough in the production well at higher flow rates results in larger water outlet temperature drop and is detrimental to the performance of the power plant installed at the surface. For an operation period of 40 years, per fracture rates of 30-50 bpd (barrel per day) provide constant power output at the surface. Figure 6 (a) shows the variation of water outlet temperature with time for different per fracture flow rates. A single fracture can be considered as a unit energy source, and because heat transfer from outside the SRV is neglected due to low thermal conductivity of the rocks, the total energy for the well is given by the number of created fractures. The economics depend partly on how fast we want to extract heat from this energy unit. Figure 6 (b) shows plot of power output versus time for the case shown in Figure 6 (a). We see that higher power is obtained for higher per fracture rates, but this exhausts the resource sooner. We also see that the power output is nearly constant over time for per fracture rates lying between 30-50 bpd. In these studies, for a fixed well length the fracture spacing (and hence the number of fractures) is varied in order to obtain uniform power output that is optimal for efficient power plant operation. While optimal fracture spacing can be found with this approach, if existing wells are used, the existing fracture spacing will be the only choice.

Figure 7 (a) shows the dependence of water outlet temperature on the number of fractures. We observe that increasing the number of fractures increases the rate of drop in water outlet temperature and hence results in more power output as seen in Figure 7 (b).



Figure 7. (a) Plot showing water outlet temperature variation with time for different fracture spacing. (b) Plot showing power output for case (a).



Figure 6. (a) Plot showing water outlet variation with time for different per fracture flow rates. (b) Plot showing power output for case (a).

Numerical Model Development using Computer Modeling Group (CMG) Software

The standard dual permeability (DK) and Multiple INteracting Continua (MINC) models cannot completely model fluid and heat flow in low permeability fractured shales. MINC models are better to some extent because they can capture the transient effects of heat flow (Rubin 2010). Our CMG model for a single fracture unit incorporates features of both DK and MINC in such a way so as to overcome their limitations. STARS module of CMG software is used for running the thermal simulation. Figure 8 shows Log SpacedLog Refined-Dual Permeability (LS-LR-DK) grid modeling technique developed by CMG. The model is patterned after that of Rubin (2010). Unlike Rubin (2010), the propped fracture is modeled at its true width because the heat transfer depends on the width of the fracture and also the grid block temperatures cannot be adjusted by using correction factors. The rock matrix is assumed to be impermeable to flow of fluids. A dual permeability model is used even though there is no mass transfer between matrix and the fracture because the matrix permeability is effectively zero. Future research in this area involves assigning finite values to porosity and permeability values to rock matrix. In this case, the heat transfer is also possible through convection in the rock matrix



Figure 8. Numerical model for a single fracture unit developed using CMG.

apart from conduction. Log refinement in the model is necessary in order to capture the movement of the thermal front in the matrix and in the fracture.

Discussion of Results

Table 2 gives the details of inputs used in the numerical model. The analytical model developed earlier is a simple heat transfer problem with temperature as the only variable and is based on the basic assumption of constant fluid properties. The analytical

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Initial temperature, °F	350
Reservoir pressure, psia	9000
Depth, ft.	12000
Thermal conductivity, Btu/ft-day-F	24.36
Heat capacity, Btu/ft ³ -F	56.06
Rock compressibility, 1/psi	10-6
Grid	1*20*5
Grid block dimensions	50 ft * 30 ft * 20 ft
Simulation run time, years	40



Figure 9. Numerical simulation runs starting for time t=0 years, t=10 years, t=30 years and t=40 years.

model has its advantages in that it can be used for a quick estimate of power output and is very effective in studying the effect of injection rate and number of fractures on the power output. By incorporating pressure along with temperature, the numerical simulation model gives a more realistic view of the heat extraction problem. The numerical model is tested for various per fracture flow rates starting from 30 bpd to 100 bpd. Numerical simulation runs at four different times 0 years, 10 years, 20 years and 40 years are shown in Figure 9. The progress of the cold thermal front from injector to producer can be noticed clearly in this figure.

Figure 10 shows a plot of per fracture flow rate variation with time. Water is produced at a constant bottom-hole pressure from the producer. The pressure gradient across the fracture is varied by adjusting the injection pressure. Pressure drop in the fracture increases with increasing flow rate. Hence in order to flow at higher rates, the bottom hole pressure needs to be lowered further. From Figure 11, we can conclude that for a bottom-hole pressure



Figure 10. Plot of per fracture flow rate variation with time. For a period of 40 years, flow rates less than 60 bpd remain constant throughout the plant operation.



Figure 11. Plot of injector and producer bottom hole pressure (BHP) variation with time.

of 10,000 psi, per fracture flow rates of 30 bpd, 40 bpd and 50 bpd are maintained constant in the fracture throughout the plant operation period.

Lowering the bottom hole pressure beyond a certain limit will turn out be uneconomical if one is planning to re-inject the produced water, after it has been extracted of its heat content, back into the formation. Re-injection, in this case, results in higher compression costs. From the results of analytical and numerical models, we conclude that it is more economical to produce at lower rates and at high bottom-hole pressure even if it results in lower power output. Adopting such a strategy will increase the life of the prospect. Moreover, producing the hot water as pressurized liquid by means of down-hole pumps has its advantages – it is easier to handle single phase flow than multiphase flow and also the pressure losses are less in a single phase flow. Steam and non-condensable gases are formed when the fluid goes below the flash

point and it could result in severe calcite scaling problems in reservoir, pipelines, valves, surface equipment etc. A pump is required to make sure the fluid always stays above the flash point. The pump setting depth in a production well is selected based on the nature of the reservoir and fluid properties. Drop in fluid temperature below a certain point can also lead to silica scaling in pre-heaters pipelines, heat exchangers and in injection wells downstream of the power plant (DiPippo 2008)W.

Figure 12 shows a plot that compares the water outlet temperature from analytical and numerical models.

Binary Cycle Power Plant Design in AspenHYSYS

Three types of geothermal power plant technologies are currently being employed depending on the nature of the geothermal resource – Dry Steam, Flash Steam and Binary Cycle power plants. Dry Steam power plants directly run on steam which drives the turbine. Flash Steam power plants are more commonly employed and they require hydrothermal fluids at high pressure and temperature (above 360°F)



Figure 12. Comparison of water outlet temperature from analytical and numerical models for different per fracture flow rates. Analytical model assumes constant water properties in the fracture, which in reality vary with pressure and temperature.

for operation. The hot fluids are flashed into flash tanks operated at lower pressure than that of the fluid. Flashing causes the fluid to vaporize and the generated vapor then drives the turbine. The non-vaporized fluid can be flashed again to generate additional electricity. Binary Cycle power plants operate with moderately hot hydrothermal fluids (below 400°F). Hot fluid from the production well exchanges heat with a working fluid (isopentane in our case) having lower boiling point than water. The vaporized working fluid



Figure 13. Basic Binary power plant.



Figure 14. Dual Pressure Binary power plant.

drives the turbine. No fluid is released into the atmosphere at all the times of operation. Low to moderate temperature formations are more common in nature, thus increasing the scope of usage of these power plants for geothermal heat extraction (DiPippo 2008). Figure 13 and Figure 14 show Basic Binary (BB) and Dual Pressure Binary (DPB) power plant models designed using AspenHYSYS.

We calculated the power output for every 50°F temperature intervals starting from 350°F to 200°F and for power plant feed rates of 30 kg/s, 60 kg/s, 90 kg/s and 120 kg/s. A DPB power plant proved to be more efficient than a BB plant. In a DPB plant, hot water from the producer passes through a series of heat exchangers one after the other (two in our case). Working fluid cycles downstream of the hot water line operate at lower pressures because the water temperature drops in every successive heat exchanger. Each working fluid cycle will add additional net power. Figure 15 shows variation of plant power output with water inlet temperature. Net power generated by the plant decreases with the decrease in water inlet temperature. Switching from Basic Binary to Dual Pressure Binary increases the net power generated by the system substantially.



Figure 15. Net power from Basic Binary and Dual Pressure Binary power plants for different water flow rates.

Economics

The Geothermal Energy Association (GEA) website provides useful information for estimating geothermal project economics. Geothermal power plants are capital intensive but they require low operation and maintenance costs and need no fuel costs. On the other hand, gas fired power plants require less capital but more operating costs in terms of fuel requirements. Use of geothermal energy can help to decrease a country's dependence on unstable fossil fuel markets. The Levelized Cost of Electricity (LCOE) in Equation (13) enables comparison of alternative technologies which have different operational investment and period of operation. The total life cycle cost includes initial investment, fuel cost, operation and maintenance costs, cost of capital etc.

$$LCOE = \frac{NPV(Total life cycle cost)}{Total life time energy production}$$
(13)

Conclusions and Recommendations

Analysis coupling both analytical and numerical flow models with a model for a surface binary cycle power plant suggests that reuse of Haynesville Shale gas production wells for low grade geothermal heat extraction after gas production is depleted appears feasible both technically and economically. Provided that sufficient connectivity can be achieved between adjacent wells, project economics are greatly aided by eliminating well drilling and completion costs. The number and spacing of hydraulic fractures created for the original purpose of shale gas production is adequate for geothermal heat extraction as well. Reusing the depleted shale gas wells for the process of geothermal heat extraction also enables left over gas production in the form of solution gas or free gas along with hot water.

The power plant model indicated that a dual pressure binary plant is more efficient and results in higher power output when compared to a basic binary cycle power plant by enabling a higher drop in water outlet temperature in the heat exchanger and hence more power output. The estimated LCOE of \$73 per megawatt hour compares favorably to a natural gas power plant.

Future Work

The analytical and numerical models developed in earlier sections made the basic assumption of impermeable matrix blocks. Assigning porosity and permeability to matrix blocks will be the first step in moving closer to reality. Bodvarsson (1974) considered a more general inter granular fluid flow model by assigning a finite value to the permeability of the rock matrix. Heat transfer between the rock matrix and the fracture can take place by convection in addition to conduction. Harlow and Pracht (1972) discussed the benefits of cooling the rock. Thermal contraction of the rock results in the creation of new cracks, creating pathways for the water to reach the uncontacted perimeter of the hot rock. The power output in this case is enhanced due to increase in convection heat transfer between water and hot rock (apart from conduction), preferential crack penetration towards hotter zones in the reservoir, greater hot rock volume available for heat transfer and fracture width increase



Figure 16. Plot showing LCOE values for different energy generating technologies.

due to rock contraction. In their work, they express concern over loss of water during circulation due to unexpected fracture growth, making it difficult to maintain pressure at the desired level for injection of hot water. Hence, there is a need to develop a more generalized thermal-geomechanical-chemical coupled model to completely study the process of geothermal heat extraction from HDR systems.

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References

- Abé, H., Duchane, D.V., Parker, R.H., and Kuriyagawa, M. 1999. Present Status and Remaining Problems of HDR/HWR System Design. *Geo*thermics 28 (4-5): 573-590.
- Bodvarsson, G. 1974. Geothermal Resource Energetics. *Geothermics* 3 (3): 83-92.
- Bodvarsson, G.S., and Tsang, C.F. 1980. Injection into a Fractured Geothermal Reservoir. Paper presented at the 1980 Geothermal Resource Council Annual Meeting, Salt Lake City, Utah, 9 September.
- Bödvarsson, G.S., and Tsang, C.F. 1982. Injection and Thermal Breakthrough in Fractured Geothermal Reservoirs. J. Geophys. Res. 87 (B2): 1031-1048.
- DiPippo, R.: Geothermal Power Plants : Principles, Applications, Case Studies and Environmental Impact, Butterworth-Heinemann, Burlington, Massachusetts, 2008.

- Edwards, L.M., Chilingar, G.V., Rieke, H.H., and Fertl, W.H.: Handbook of Geothermal Energy, Gulf Publishing Company, Houston, Texas, 1982.
- Fisher, M.K., Heinze, J.R., Harris, C.D., Davidson, B.M., Wright, C.A. et al. 2004. Optimizing Horizontal Completion Techniques in the Barnett Shale Using Microseismic Fracture Mapping. Paper SPE 90051 presented at the 2004 SPE Annual Technical Conference and Exhibition, Houston, Texas, 26-29 September.
- Gringarten, A.C., Witherspoon, P.A., and Ohnishi, Y. 1975. Theory of Heat Extraction from Fractured Hot Dry Rock. J. Geophys. Res. 80 (8): 1120-1124.
- Harlow, F.H., and Pracht, W.E. 1972. A Theoretical Study of Geothermal Energy Extraction. J. Geophys. Res. 77 (35): 7038-7048.
- Pope, C.D., Palisch, T.T., Lolon, E., Dzubin, B., and Chapman, M.A. 2010. Improving Stimulation Effectiveness: Field Results in the Haynesville Shale. Paper SPE 134165 presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy, 20-22 September.
- Robinson, E.S., Potter, R.M., McInteer, B.B., Rowley, J.C., Armstrong, D.E. et al. 1971. A Preliminary Study of the Nuclear Subterrane.
- Srikanth, T. 2011. Heat Transfer Applications for the Stimulated Reservoir Volume. Masters Thesis, Texas A&M U., College Station, TX.
- Thompson, J.W., Fan, L., Grant, D., Martin, R.B., Kanneganti, K.T. et al. 2010. An Overview of Horizontal Well Completions in the Haynesville Shale. Paper SPE 136875 presented at the Canadian Unconventional Resources and International Petroleum Conference, Calgary, Alberta, Canada, 19-21 October.
- Wang, J., and Liu, Y. 2011. Simulation Based Well Performance Modeling in Haynesville Shale Reservoir. Paper SPE 142740 presented at the SPE Production and Operations Symposium, Oklahoma City, Oklahoma, 27-29 March.