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PROPERTIES OF GEOPRESSURED BRINES AND WELLS IN THE GULF COAST AND OPPORTUNITIES FOR INDUSTRIAL/RESEARCH PARTICIPATION*

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ABSTRACT

Geopressured reservoirs exhibit pressure gradients in excess of the normal hydrostatic gradient. (In the Gulf Coast area the normal gradient is 0.465 psi/ft.) Pressures may approach lithostatic pressure and have been measured as high as 1.05 psi/ft in the Gulf Coast area. Geopressured basins exist worldwide and in a number of U.S. locations, east, west, north and south. The Gulf Coast area has been studied extensively and is the subject of the DOE geopressured-geothermal research at present.

The assumed ranges in resource characteristics include: depth from -12,000 to > -20,000 feet, brine flow rate from 20,000 to 40,000 bpd, temperature from 300 to 400^{o}F, bottomhole pressure from 12,000 to 18,500 psi; salinity from 20,000 to 200,000 mg/L, gas-water ratio from 40 to 80 scf/bbl., and condensate from a trace to production.

Energy in the geopressured resource includes gas, thermal, and hydraulic energy. It has been estimated that there are 6,000 quads of methane and 11,000 quads of thermal energy in the Gulf Coast area geopressured-geothermal reservoirs. Estimates run as high as 50,000 quad for the thermal energy (Wallace et al, 1978).

Present industrial interest in the Pleasant Bayou and Hulin wells includes: desalination plants, an economic study by a power company for regional use, use of generated electricity by a coalition of towns, aquaculture (catfish farming) research program, and an unsolicited proposal for enhanced oil recovery of heavy oil. Direct uses of the hot brine cover dozens of industries and processes. An example of multiple uses in the USSR is shown. Outside agency interest includes the U.S.G.S., N.S.F., G.R.I., and possibly other areas within DOE. A research spin-off: a sensitive in-line benzene monitor has been designed by USL and will be tested in the near future. An in-line pH monitor is also under development for the harsh conditions of the geopressured-geothermal wells.

The first planning meeting for an Industrial Consortium addressing the use and participation in the geopressured resource will be held September 1, 1989, at the University of Texas. Please contact Dr. Myron Dorfman at UTA or me if you or your company are interested in participating.

INTRODUCTION

The most diagnostic aspect of geopressure-geothermal resources is their fundamental identity: They are simply superheated ground water in high-pressure aquifer systems (Jones, 1975). Gulf Coast reservoir pressures and temperatures may exceed the local gradients by a factor of 2, resulting in a general bottomhole pressure range of 12,000 to 18,000 psi and a general temperature range of 300 to >>400^{o}F; measured values may be considerably higher or lower.

Geopressured basins occur worldwide and in many areas of the United States (Fig 1). The Geopressured-Geothermal Program sponsored by the DOE has concentrated in the northern Gulf of Mexico where the reservoir conditions are largely a result of rapid sedimentation and compaction of more than 50,000 feet of Cenozoic clastics.

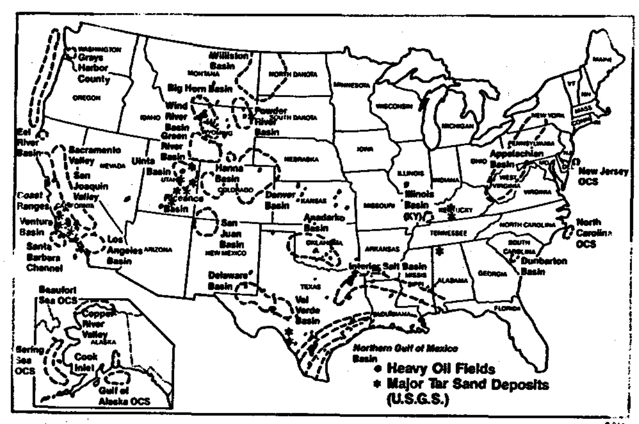

Fig. 1. Index map of geopressure locations with heavy oil and tar sands (Modified after Strongin, 1981; Meyer U.S.G.S., 1989).

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Earlier in this program, the Wells of Opportunity assisted in delineating the geopressured-geothermal fairways in the Texas and Louisiana Gulf Coast area and in confirming the resource energy estimates. The U.S.G.S. has estimated that there are 6,000 quad of energy in the geopressured geothermal Gulf Coast gas and 11,000 quad of thermal energy (Wallace et al., 1978). This compares with 300 quad in coal seam gas, 500 quad in Devonian shale gas, and 600 quad in western tight gas sands (1 quad equals 1 trillion cubic feet of gas). The present DOE Design Wells in Texas and Louisiana are providing the additional operational and research basis to achieve the ultimate goal of efficient electric energy extraction technologies capable of greater than twenty percent thermal efficiency by 1992.

GEOLOGY

An example of the geology associated with the Gulf Coast geopressured-geothermal wells can be seen in the geology surrounding the Hulin Well located in Vermilion Parish in Southern Louisana in one of the designated geopressured fairways (Fig. 2). These fairways are all located south of the Tuscaloosa Trend where the Tuscaloosa rocks outcrop parallel to the continental margin. The Hulin Well is the deepest, hottest well in the geopressured program. Workover of the Hulin Well was recently completed; testing will continue into FY-90. A structure map on the top of the Lower Planulina Section shows the Hulin Well located off structure at -15,400 feet (Fig. 3). Major down-to-the-basin faults separate the Hulin Well reservoir from the Erath Field on the north, the Tigre Lagoon Field on the northeast, and the Boston Bayou Field on the south. No fault has been identified on the southwest. A north-south cross section (Fig. 4) shows the Hulin Well, #79, flanked by two oil wells, #98 and #61, on the north and south (Fig. 5). These wells were completed at a higher horizon than the Hulin Well; the Hulin Well is the deepest in the area. The original total depth was >21,000 ft. The step faults can be identified on this cross section, including a fault cutting the Hulin Well. The thick Planulina sandstone of Miocene age has been interpreted as a submarine canyon depositional system composed of three submarine fans. The Hulin Well is located in the thickest fan lobe in 1,500 feet of massive sand with shale partings. If this interpretation by the University of Texas (Tyler, 1988; and Hamblin, 1988) is correct,

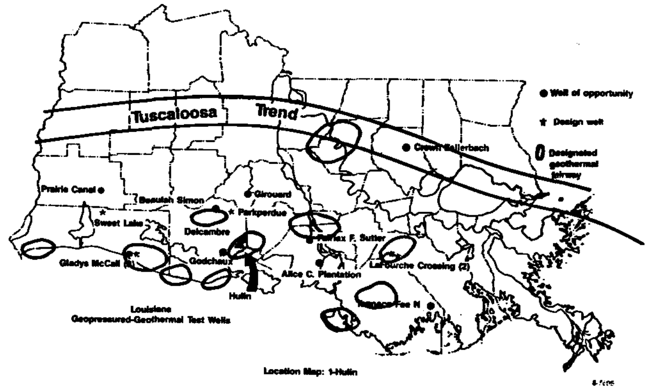

Fig. 2. Location of identified geopressured fairways and the Hulin Well.

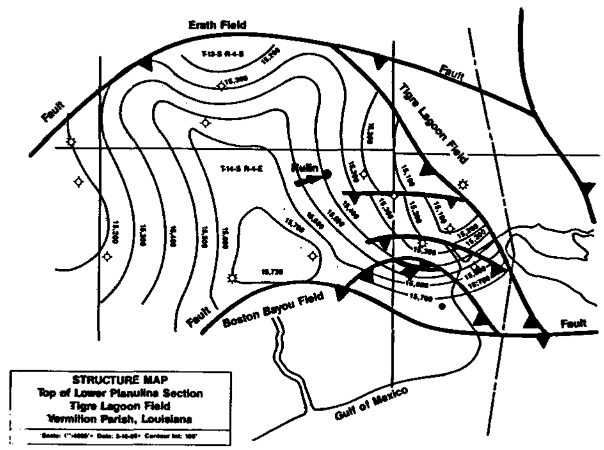

Fig. 3. Structure map on top of the Lower Planulina Section showing the Hulin Well (UTA).

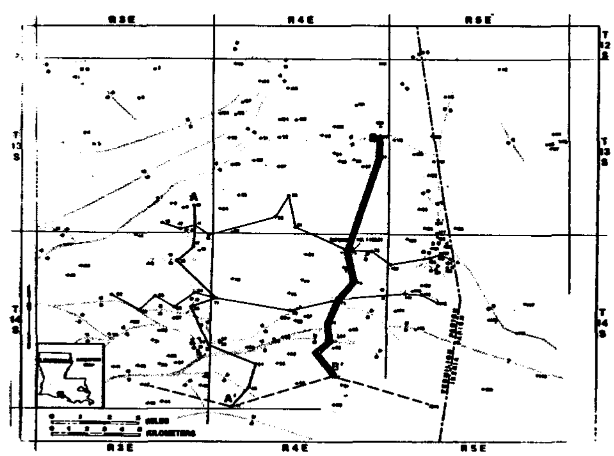

Fig. 4. Location of cross section B-B' (UTA).

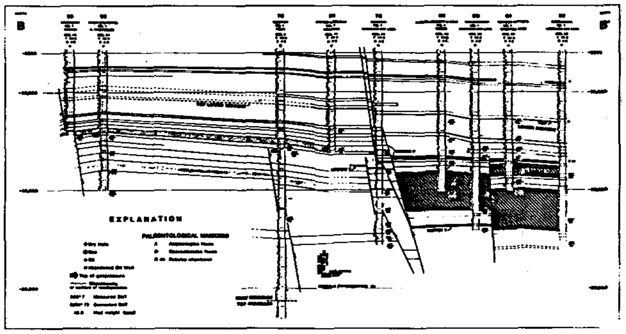

Fig. 5. Structural-stratigraphic cross section B-B[1] (UTA).

the reservoir body will be elongated north-south and in the east-west direction it will be narrowly confined by the steep submarine canyon walls. The bottom 20 feet of the basal 700 ft sand have been perforated in the Hulin Well and briefly flowed to 10,000 bpd (Eaton Operating Company, 1989).

In modeling the Hulin reservoir the lack of structural control is an obstacle. To improve upon the information base, the Louisiana State University is obtaining the seismic lines shown in Fig. 6 (John, 1989). This will provide the basis for improved structural interpretation and reservoir volume estimations.

Gamma Ray and Resistivity Logs of the Hulin sand of interest are shown in Fig. 7. The University of Texas has interpreted the logs to suggest possible free gas or condensate in the upper portion of the thick sand section (Dunlap, 1989).

Estimated porosity for the Hulin Well is 15 percent (Randolph, 1989); preliminary permeability estimates range from 20 md to 200 md (Randolph, 1989; Eaton, 1989).

BRINE/WELL CHARACTERISTICS

As sedimentary basins evolve through geologic time the majority of basins go through a geopressured phase of development. The geopressure zone coincides with the 2nd of the 3 shale dehydration phases. It is thought that this is also the zone in which most horizontal fluid hydrocarbon migration takes place. With continuing geologic time the liquids are lost and the basin outgasses, just as it is anticipated that all planets in the universe lose their fluids and gases. No seal is leakproof and eventually a basin will become normally pressured or underpressured.

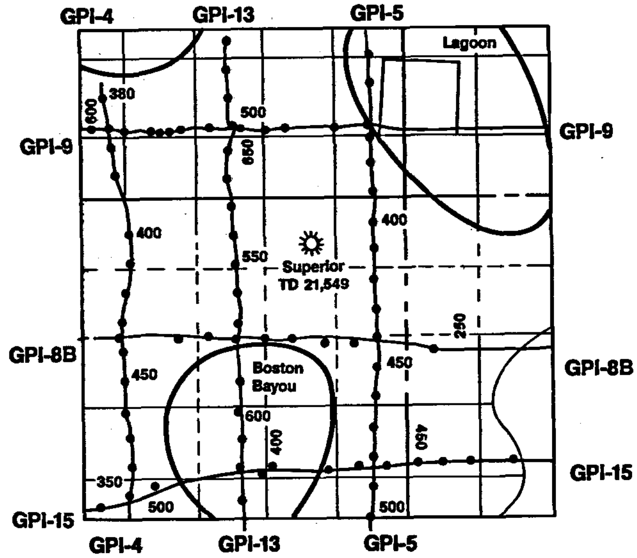

Fig. 6. Location of seismic lines for the Superior Hulin Well (LSU).

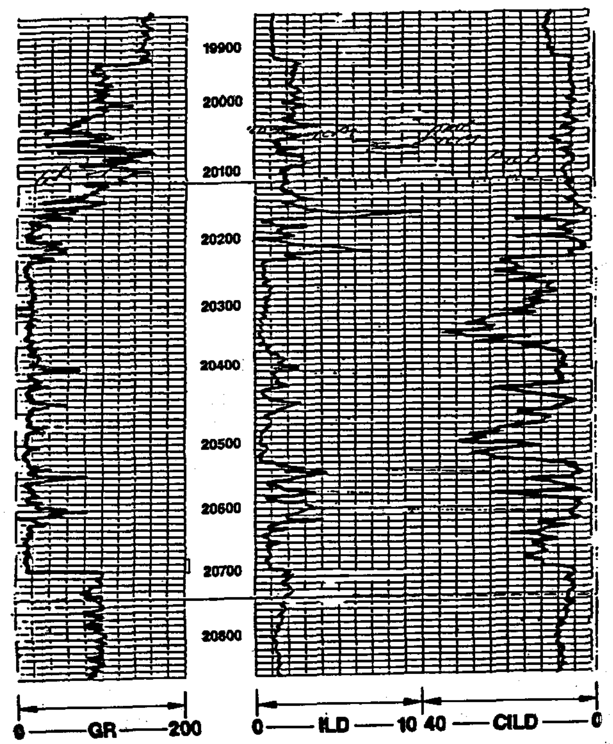

Fig. 7. Gamma Ray and Resistivity Logs for the thick geopressured sand of interest in the Hulin Well (EOC).

The hydrocarbons encountered in geopressured wells generally follow classical thermal maturation. Heat is the main factor contributing to the generation of fluid and gaseous hydrocarbons (oil and gas). With time and temperature applied to terrestrial (gas-prone) and marine (oil-prone) source material, first a small amount of gas is generated, followed by increasing amounts of oil. When the "cracking" point is reached the oil is broken down leaving gas and condensate and eventually, only dry gas (Fig. 8). The geopressured zone in the Gulf Coast area generally is found in the more gaseous maturation levels, sometimes in the oil-phase-out or condensate level, and if deeper, in the dry gas level. The Gulf Coast area hydrocarbons are highly influenced by terrestrial source material and thus tend to result in high gas content (Negus-de Wys, 1984).

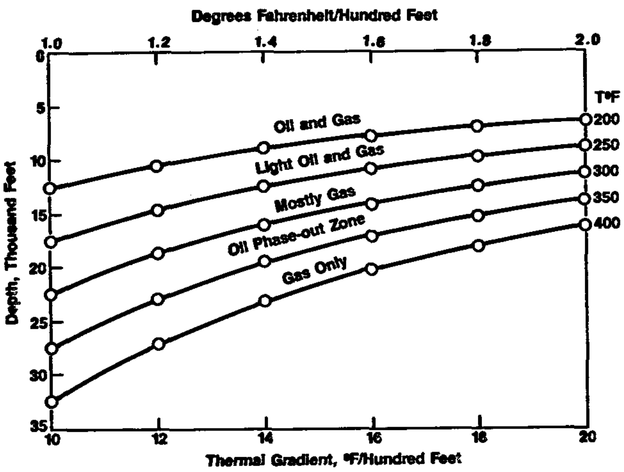

Fig. 8. Physical state of hydrocarbons as a function of depth and geothermal gradient (Fertl, 1972).

The resource characteristics of the geopressured wells generally fall within the ranges shown in Fig. 9. The Pleasant Bayou Well, located in Brazoria County, Texas, south of Houston, was perforated at 14,644 to 14,704 feet, and has a surface temperature of 255^{0}F. It has been flowing hot brine at about 20,000 bpd since June 1988. The Hulin Well in Vermilion Parish, Louisiana, has characteristics at the hotter, deeper end of the range. It is >20,000 feet deep, has an estimated 340^{0}F formation temperature, 17,850 psi bottomhole pressure, and salinity of 120,000 mg/L. The expected gas/water ratio

Depth (feet)	**12,000 - >20,000**
Flow rate (bpd)	**20,000 - 40,000**
Temperature (°F)	**300 - 400**
Pressure (BH psi)	**12,000 - 18,500**
Salinity (mg/L)	**20,000 - 200,000**
Gas/water (SCF/bbl)	**40 - 80**
Condensate	**Trace - Producing well**

Fig. 9. Ranges in geopressured resource characteristics in the Gulf Coast area assumed for cost estimates (Negus-de Wys, 1989).

is 33.6 to 37 scf/bbl at the estimated salinity and temperature for the well (Randolph, 1989; Faulder, 1989; Blount, 1983). Fig. 10 shows the solubility of methane in fresh water (Sultanov, et al, 1972). At a bottomhole pressure of 17,850 psi and a formation temperature of 340^{0}F, the solution gas/water ratio would be estimated at about 80 scf/bbl. However, with 180,000 mg/L TDS (total dissolved solids) or 120,000 mg/L chlorides as in the Hulin Well, the gas/water ratio will be reduced to approximately 33.6 to 37 scf/bbl. Additionally, free gas and condensate may be encountered (Dunlap, 1989). Testing is in the very early stages in the Hulin Well.

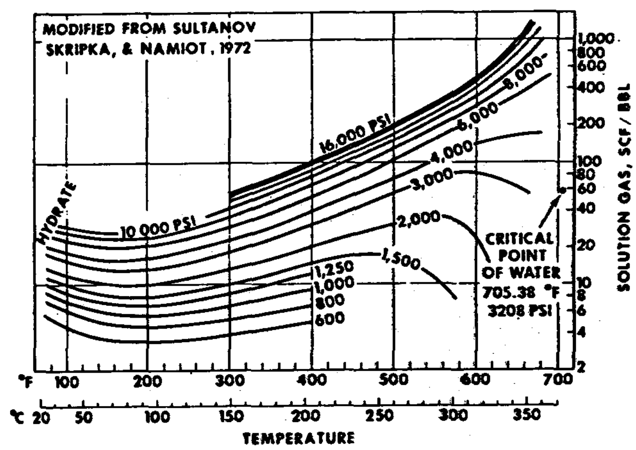

Fig. 10. Solubility of methane in fresh water at elevated temperatues and pressures (Sultanov et al, 1972).

ENERGY

The various energy forms available from the geopressured resource include gas, thermal, and hydraulic energy. The dissolved methane can be separated and sold, compressed, liquefied, or the methane converted to methanol. The thermal energy can be converted to electricity as is being done at the Pleasant Bayou Well or diverted to direct use processes. The Hulin Well with a temperature of 340°F could thermally support any of the processes shown in Fig. 11. Hydraulic energy can also be converted to electrical energy with a hydraulic turbine.

The estimate of 6,000 quad of gas and 11,000 quad of thermal energy in the Gulf Coast will *only be realized with industrial participation* and development. The bottom line to industry is profit at some point in a reasonable time frame.

An updated analysis of cost factors, assumptions, and resulting energy cost and supply is in progress at INEL. Preliminary computations suggest that the range in cost per KW-h for thermal conversion to electricity is 16 cents to 48 cents/KW-h. These figures depend upon the resource parameters, capital cost assumptions, methods of energy conversion and a myriad of other financial input data. The 48 cents/KW-h would apply to a Pleasant Bayou type well; the 16 cents/KW-h is applicable to the Hulin resource. With modifications in conversion methods (recuperative regeneration high efficiency system), these costs could conceivably be reduced to 6 cents to 18.5 cents/KW-h (Negus-de Wys et al. 1989). Additionally, there is the sale of free gas and direct use to tip the economic scales to a profit margin. The following areas of industrial interest and research suggest the reality of such a combination (Negus-de Wys et al. 1989).

INDUSTRY/RESEARCH INTEREST

The Geopressured-Geothermal Program is entering a phase of industry participation and cosponsored research. The Brine Chemistry Consortium, in which EG&G/INEL participates, is a direct outgrowth of supporting research on brine chemistry of scale formation and corrosion control in energy production from geopressured/geothermal wells in the DOE program. In these wells large volumes of brine are produced at high temperatures and

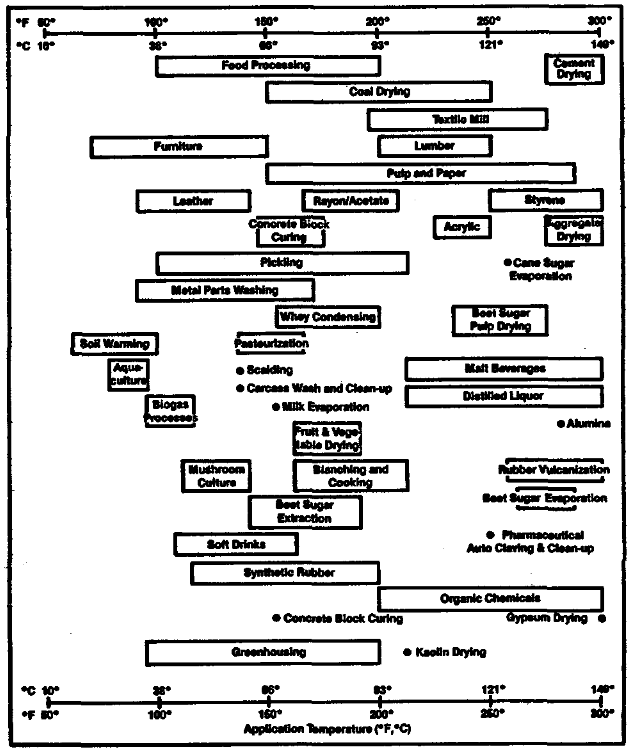

Fig. 11. Application temperature range for some industrial processes and agricultural applications (Anderson and Lund, 1979).

pressures. The brines are produced at depth; the pressure falls as they flow up the production tubing and as they flow through the surface equipment. In geopressured production the flow rate is generally fast and the fluid column is essentially all liquid; therefore, the temperature drop is negligible. In geothermal energy production the pressure drop normally exceeds the temperature drop with respect to their effects on the scale-formation state of the brine. The consequence of this production regime is that most geothermal-geopressured wells tend to be corrosive at the bottom to the middle of the tubing, and scaling at the top of the tubing and in the surface equipment. If the temperature drops significantly before the pressure decreases, the brine will become subsaturated with respect to calcite scale formation and consequently will be highly corrosive (Tomson, 1989).

Of the two problems, scale formation and corrosion, scale formation tends to occur earlier and is generally more easily prevented. The time frame for the formation of scale is days to weeks. Corrosion generally does not cause severe problems for several months to a year, even in a corrosive well environment. Scale can generally be prevented by one, or less parts per million of phosphonic or polycarboxylic acid. Such inhibitors are called "threshold" inhibitors. They can be delivered either by squeezing the chemical back into the formation and then letting it be released slowly or by continuously injecting chemicals toward the bottom or middle of the tubing with small "treat" strings (about 1/4 inc. OD). Each method has significant advantages and disadvantages. The treat strings permit the composition and type of the inhibitor to be varied. The squeeze can be performed after the well has been completed and has the potential of preventing porosity loss in the formation near the well bore.

Corrosion control can be more difficult and expensive. To control corrosion with chemical inhibitors sometimes takes up to 100 mg/l of synthetic chemicals. Also, high alloy stainless steels are used to avoid corrosion associated with brine production. Stainless steels are generally most effective in oxidizing environments wherein heavy metal oxides form protective coatings which act as physical barriers to corrosion (Tomson, 1989; R. Miller, 1989).

At the Pleasant Bayou geopressured well south of Houston a 1MWe hybrid power system is being installed in cooperation with EPRI (Electrical Production Research Institute) to convert thermal energy to electricity. This unit will convert the thermal energy in the brine to electricity using heat exchangers with isobutane. Inquiries of a preproposal nature have been received for desalination facilities and the Lower Colorado River Authority (LCRA) is interested in evaluating the resource for regional use. At the Hulin Well a coalition of small towns is interested in the electricity from thermal conversion. There is interest in a group proposal at the University of Southwestern Louisiana in an aquaculture project including catfish, crayfish, alligators, and greenhouses (Meriwether, 1989). This kind of diversified direct use has proven viable for thermal projects and could tip the balance of the scales in geopressured energy use to reach an economically viable complex (Anderson and Lund, 1979; Lunis, 1989). An example of this type of cascading thermal energy use is shown in Fig. 12 (Dvorov and Dvorov, 1988).

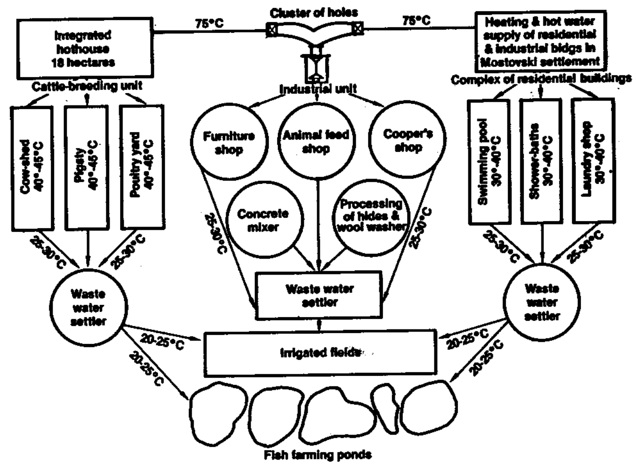

Fig. 12. Direct use complex in the USSR (Dvorov and Dvorov, 1988).

Lastly, there is the TEOR (Thermal Enhanced Oil Recovery) potential for moving heavy oil with hot geopressured brine. In Fig. 1 the geopressured basins in the United States are shown with the occurrence of recoverable heavy oil and tar sands (Negus-de Wys, 1989).

The San Joaquin Basin in California provides most heavy oil production in the United States and almost all TEOR output in the U.S. (400,000 bpd). Thermal recovery accounts for about 3/4 of all U.S. EOR production. In Kern County alone (San Joaquin Basin) there are 2.5 billion bbls of recoverable heavy oil reserves at depths of -1,000 to -3,000 feet with API gravities of 12 to 23^{o}. The major operators are Texaco, Chevron, Mobil, and Unocal; predominant recovery method is cyclic steam (Williams, 1988).

The western part of The San Joaquin Valley has high geopressures, very low salinity waters, geothermal gradients 2 times normal, and methane content of 30 to 40 scf/bbl (Strongin, 1981).

If the use of geopressured brine in moving heavy oil can provide even a 5-10% edge economically, it will be a viable industrial use. Environmentally, the use of geopressured brine would be a cleaner process than the present methods.

INDUSTRIAL CONSORTIUM

The Industrial Brine Consortium, discussed above, is led by Dr. Mason Tomson at Rice University and meets twice a year. Members share in the applied brine research that addresses scaling and corrosion. Membership includes Exxon, Texaco, Zapata, Chevron, Champion Chemical, Conoco, Wechem (Amoco), EG&G/INEL, and GRI. This group that is a spin-off from the geopressured research is now headed toward Research Institute status cosponsored by GRI.

Additional industrial participation is now being sought for the utilization and cosponsorship of the geopressured energy resource. An industrial consortium planning meeting to develop a consortium with such a goal will be held September 1, 1989 at the University of Texas. Cochairmen are Dr. Myron Dorfman and Dr. Charles Kreitler (UTA), Dr. Charles "Chip" Groat (LSU), Dr. John Meriwether (USL), and Dr. Jane Negus-de Wys (INEL). Interested companies or parties are invited to contact any one of the cochairmen.

CONCLUSIONS

1. The DOE Geopressured-Geothermal Program has entered the phase of industrial participation and cosponsorship.

2. Preliminary ranges for the characteristics of the geopressured brines and wells in the Gulf Coast area in Texas and Louisiana have been established.

3. Geopressured energy forms include gas, thermal, and hydraulic energy.

4. Utilization includes selling the separated gas, compressing the gas, liquefying the gas, making methanol from methane, converting thermal energy to electricity, direct use of thermal energy for industrial processes, and converting hydraulic energy to electricity.

5. Preliminary inquiries on the part of industry and cosponsored research include use of the electricity from thermal conversion for regional use and small town use, direct use of thermal energy in aquaculture, desalination facilities, and thermal enhanced oil recovery.

6. Inquires are invited concerning the industrial consortium planning meeting for the utilization, participation, and cosponsorship of the geopressured resource (208-526-1744).

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