

## STEAM STIMULATED ENHANCED OIL RECOVERY BY SPI 2400S

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## ABSTRACT

It is estimated that synthetic crude bitumen and heavy oil will be the dominant crude oil supply source in Canada within 10 years. However, the realization of this projected oil supply scenario is contingent upon application of appropriate oil production enhancement technologies. Consistent with the above and the nation's quest for energy self-sufficiency via EOR applications, Rocanda has developed and successfully field-tested a steam-bearing additive SPI 2400S: a patented amide based oil-soluble surfactant that is stable at extremely high temperatures (up to 445°C).

When added to steam, there are significant oil production increases and extremely favourable economic benefits. The special features of this surfactant, its mechanisms of oil recovery action, application procedure and field case histories will be presented and the economic consequences to operations discussed.

## INTRODUCTION

Steam stimulation/steam flooding technology is undoubtedly the most effective enhanced oil recovery (thermal) technique currently in use. Since its advent in 1959, steam processes have quickly gained recognition as most promising technological achievement, possessing a definite potential for the economic development of vast tar sand resources in Alberta, large conventional heavy oil reservoirs in Saskatchewan as well as light oil deposits worldwide. Although cyclic steam injection is less expensive than steam flooding, the sizeable increase in oil recovery could be achieved only by means of continuous steam injection. At the same time, cyclic steam stimulation procedures are believed to be an indispensable step initiating production from newly drilled wells and establishing communication between them. After the production from these recently initiated cyclic steam operations declines, the conversion to steam flooding normally follows.

Currently, steam stimulation and steam flood projects are responsible for approximately 80% of the Enhanced Oil Recovery production in the United States. This growth has occurred over the past three decades despite the fact that the performance of the process has proven sensitive to factors such as reservoir heterogeneity, adverse mobility ratios, gravity override and steam channeling. Total volume of oil produced in the United States by cyclic steam and steam drive since 1959 has well exceeded one billion barrels. Steam injection technology has also had a large impact on heavy oil resources in the Athabasca, Peace River, Cold Lake and Lloydminster areas of Canada.

However, the economic viability of steam stimulation/drive technology should not be taken for granted. The limitation on oil recovery through steam injection arises from a limited vertical sweep of the reservoir, the presence of a significant water column beneath the oil, insufficient thermal impact caused by excessive heat losses, etc.

Important reservoir and/or process parameters influencing the use and efficiency of steam operations are as follows.

- A high oil saturation is required because of the intensive use of energy for steam generation.

- A greater thickness of the reservoir increases the thermal efficiency since the fraction of the heat lost to overburden and underburden formations will vary inversely with the reservoir thickness.
- The higher the injection rate, the lower the heat losses since these increase with the square root of time.
- The higher the injection rate for any given pattern size, the shorter the time of operation.
- A high injection pressure (determined by higher injection rate) entails a high steam temperature and as a result, higher heat losses.
- The higher the steam pressure, the smaller the fraction of the total heat of steam in the form of latent heat of vapourization, which results in lowering the process efficiency.

All the above factors dramatically affect the economic viability of a steam injection operation. The overall effectiveness of a steam operation is usually rated by the ratio of oil produced to steam injected, in volumes per volume. The theoretical ratio at which the energy produced is equal to the energy consumed is 13 – 14 barrels of steam per barrel of oil (with overall thermal efficiency in generation and distribution being 75 %). The economic limit is about 8 barrels of steam per barrel of oil for most operations in the U.S.A. and Canada.

In absolute terms, about 200-300 bbls of oil per acre-foot of reservoir must be burned to generate the required steam in steam flooding operations and recover up to 40-50% of original (remaining) oil in place. Steam stimulation is significantly more thermally efficient than steam drive, using only 20-30 barrels of oil per acre-foot, but producing only 5-15% of oil in place.

As can be drawn from the above discussion, new technological ideas and advances are needed to extend the range of economically successful steam injection methods. One of the most important innovations along this line is the use of additives.

#### THE USE OF STEAM-BEARING ADDITIVES IN STEAM INJECTION

Steam additives are used for various purposes. First of all, surface-active type additives may substantially reduce interfacial tension thus promoting higher displacement efficiency. They may also create better injectivity to steam and smaller resistance to flow of oil during production cycles. Furthermore, steam additives (in steam flooding mode) may facilitate the creation of channels for steam to communicate between injectors and producers. This phenomenon is of great importance in many heavy oil and bitumen reservoirs with very high initial oil saturation. Finally, a variety of additives (foaming materials) can be utilized to provide some plugging of the steam filled zones (depleted of oil) so that the injected steam is diverted into those parts of the reservoir, which are still saturated with oil (improved reservoir sweep).

Aside from the aforementioned additives, the injection of a noncondensable gas with steam may improve thermal oil recovery as a result of higher reservoir pressure and displacement efficiency of oil in the presence of trapped gas (during backflow) as well as better heating of a larger portion of the formation.

Although there are a lot of studies dealing with steam-bearing additives, it is not a simple task to isolate a class or group of additives, which can be recommended for most future applications. The problem is that some additives have shown very promising laboratory test results, but shown disappointing field results. That is why we want to concentrate on the use of a chemical additive, which has been extensively tested over a few years in variable field conditions both domestically and abroad with a proven success record. This additive is called SPI 2400S.

#### STEAM STIMULATED ENHANCED OIL RECOVERY BY SPI 2400S

SPI 2400S is a patented, amide-based, oil-soluble surfactant (steam additive) that is stable at temperatures of up to 445°C (833°F). Needless to say, thermal stability is a key feature of any additive

applied in steam injection technology. Consequently, the SPI 2400S thermal stability level makes it unique amidst substances proposed for commercial use.

As mentioned above, one of the most important functions of an additive in the course of steam stimulation flooding is an increase of steam injectivity and/or improvement of oil productivity. Both of these objectives are effectively realized by means of SPI 2400S application. The improved steam injectivity is believed to result from superior steam distribution caused, in turn, by a continuous wettability control (maintaining preferentially water-wet environment) as well as reduced interfacial tension, which makes the propagation of the steam bank (slug) easier.

The improved oil production is inferred to be a result of a synergistic mechanism incorporating reduced interfacial tension, wettability control, emulsification as well as foam forming processes. While the impact of reduced interfacial tension and wettability control factors are self-explanatory, the emulsification and foam forming "components" are noteworthy.

When being injected along with steam, SPI 2400S facilitates an emulsification process resulting in the development of a water-external emulsion (this type of emulsion forms, provided the SPI 2400S concentration is relatively low). Oil-in-water emulsion is known to have much lower viscosity and accordingly higher mobility than reservoir oil. Consequently, the resistance to flow of oil (both entrained in the flowing steam and as oil-in-water emulsion) drastically reduces in addition to a favourable effect of reservoir (oil) heating. Combined with lowering interfacial tension, the above mechanism results in sizeable increase in oil production, provides an improved oil-steam ratio and upgrades the process economics. It should be noted that due to the SPI 2400S impact, oil-in-water emulsion breaks clean upon production without incurring any significant problems related to its processing.

As the SPI 2400S concentration increases another mechanism, a foam forming, is conceivable and needs yet to be studied. Although a foam presence is unlikely desirable in the course of steam stimulation (because it may entail the rise of resistance to flow over production cycle), it might have a certain positive impact on the steam-flooding mode: diversion of steam into unswept zones and blocking swept channels. This complicated effect of SPI 2400S concentration is not quite clear yet and needs to be investigated both in laboratory and in field tests.

Certain important features of the SPI 2400S chemical nature deserve to be mentioned. SPI 2400S is a non-ionic surfactant with C18 structure having a characteristic dimethylamide of an unsaturated fatty acid group as active ingredient.

It is well known that, non-ionic surfactants are very little affected by presence of water-soluble salts, irrespective of their (salts) concentration. Therefore, the SPI 2400S can be successfully applied in a wide range of reservoir brine salinities. In addition, SPI 2400S contributes to corrosion control by forming a very thin protective film on metal surfaces. Furthermore, since the SPI 2400S (dimethyloleoamide) is highly active (95%), its typical concentration for most field applications is very low (8-20 ppm range), equivalent to the consumption of only 1 litre SPI 2400S per 100m<sup>3</sup> steam. Needless to say that the economics of SPI 2400S technology is especially attractive since the process does not require sizeable expenses, whereas observed increase in oil production and/or steam injection, as a rule, is very significant.

Table 1 and Figure 1 present data illustrating some field applications of SPI 2400S and observed production increase attributed primarily to the use of the additive. It is noteworthy that the production increase may have resulted from either improved backflow of oil during production cycle, or better steam injectivity, during injection cycle, or both mechanisms combined. Also, as can be seen from Table 1, the SPI 2400S application turns out to be most efficient over intermediate and late cycles, when the contribution of natural reservoir energy becomes less pronounced.

#### THE ECONOMICS OF SPI 2400S APPLICATION

Table 2 contains the results of economic evaluation of the SPI 2400S application in the Cold Lake area thermal pilot. Note, that all three nodes of operations presented have the same capital costs. It just reflects the fact that the SPI 2400S use incurs some moderate increase in operating costs without affecting the capital expenditures.

Although some facets of SPI 2400S's impact towards improving oil production should be further studied (mainly, in laboratory tests), its field applications are supported by a proven success in a variety of conditions and in different areas of the world. The low cost of the SPI 2400S operations makes them especially attractive for massive applications on a field (pool) scale basis.

#### SUMMARY

Steam stimulated enhanced oil recovery by SPI 2400S is an efficient mechanism having a proven success record. The relative simplicity of application coupled with hard economic advantages makes this process highly desirable.

TABLE 1

## FIELD PRODUCTION DATA FROM SPI 2400S APPLICATION

Field	Type of Application	Observed Production Increase
Kern County, California	Steam Stimulation, Early Cycle Enhancement	104%
Lloydminster, Alberta	Steam Stimulation, Intermediate Cycle Enhancement	58%
Lloydminster, Alberta	Steam Stimulation, Late Cycle Enhancement	45%
Cold Lake, Alberta	Steam Stimulation Flood	53%
Piritai Field, Orinoco Region, Venezuela (2 tests)	Early and Intermediate Cycles of Steam Stimulation	>1,000%

TABLE 2

## ECONOMICS OF STEAM STIMULATION/FLOODING WITH AND WITHOUT SPI 2400S TECHNOLOGY

## THERMAL PILOT, COLD LAKE, ALBERTA

Development Scenario	Capital Cost (M\$)	Ultimate Oil Prod. Bbls.	Net Present Value Disc. Cash Flow (M\$ at Disc. Rate)			After Tax	
			0%	15%	20%	Rate of Return (%)	Payout Years
1. Base Case: No SPI 2400S	900	138,000	197	-50	-110	11.4	3.1
2. SPI 2400S Process with 10% Oil Production Increase	900	152,000	334	63	-3	19.8	2.6
3. SPI 2400S Process with 20% Oil Production Increase	900	164,000	454	151	78	26.2	2.4

**Figure 1**  
**Cold Lake SPI 2400S Thermal Project**

