INTEGRATED OILFIELD SOLUTIONS WITH HEAT MANAGEMENT SYSTEMS

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I. Abstract

The increasing shortage of easy to produce oil has had a profound impact on the oil industry. The end of cheap oil has led to increasing reliance on unconventional resources and technologies. Enhanced recovery methods are being employed to recover heavy, waxy and gas laden oils which do not readily flow up a well. As the oil industry focuses on meeting the energy requirements of the new millennium, thermal solutions become a critical component in the discovery, production, transportation, distribution and refining of oil. This paper provides an overview of the heat management needs of various segments of an oilfield, analysis methods to determine heating requirements and heating technologies available to meet the needs. We will introduce advancements in simulation studies that can be used to model the thermal behavior of various oilfield components. Further, this paper discusses various aspects of an integrated oilfield heat management system to address heating requirements for the entire oilfield.

II. Introduction:

A reduction in the world’s dependence on oil and gas as a major energy source is not forecast to occur in the near future. While energy conservation is considered a critical strategy to extend the supply of oil and gas for future generations, rapid economic growth in emerging markets such as China and India has resulted in increased demand for oil and gas. It has become abundantly clear that conservation alone is not going to be the answer. As the price of oil and gas reach record levels, the latest models in energy production economics present a new picture of what constitutes viable exploration and development methods. Energy companies are now looking to develop difficult oilfields that in the past would have been considered uneconomic, and they are reopening abandoned fields with tertiary recovery methods. The exploration and development of oilfields with heavy, waxy, difficult oil has offered a new lease on life for many energy starved countries in the world.

III. Definitions

Figure 1 illustrates typical oilfield components that may require heat management when the reservoir contains difficult oil. Provided here are a few definitions for added clarity.

Downhole heating: Heat tracing applied to the production tube of a well, typically starting at the wellhead and tracing the upper 500 to 2000 meters of the well.

Heat tracing: a heating medium, commonly an electric heating cable, applied to the surface of a pipe, valve or tank to maintain the contents of the pipe at a temperature that is higher than the surrounding ambient temperature.

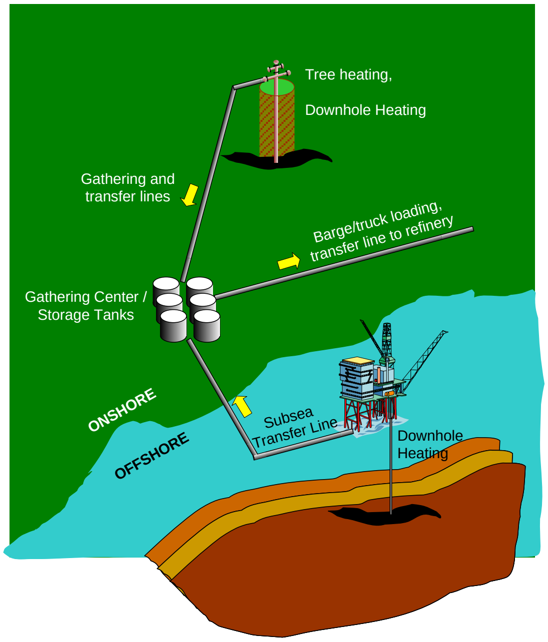

Figure 1: Illustration of an oilfield

Pre-insulated piping: A method of pipeline construction where thermal insulation and a protective outer jacket are applied to pipe spools in a factory setting, then delivered to the construction site for assembly. Heat tracing can be factory applied as well. Pre-insulated piping is a means of reducing field labor while improving insulation and jacket quality.

Skin effect heating: A method of electric heat tracing utilizing a small diameter steel tube containing an electric cable, whereby the steel tube forms a significant part of the electric heating circuit.

Tree heating: Heat tracing applied to the well tree.

IV. Past Flow Assurance Methods

Even where the reservoir temperature is relatively high, cooling in the production tube due to geothermal gradient and gas expansion can cause hydrates to form, wax to build up and viscosity to increase. Some fields simply cannot be produced without taking exceptional measures to enable flow. A number of different flow assurance methods have been used in the past to keep oil flowing up the well and through the pipelines, with varying degrees of success.

A common method to combat plugged wells is to use mechanical scraping. In some cases, scraping has had to be carried out more than once a day. This method requires interruption of production and constant involvement of skilled labor and expensive equipment.

Another means of keeping the wellstream flowing is to inject chemicals to reduce viscosity and inhibit wax and hydrate formation. This method requires a constant supply of chemicals, and can present some additional environmental issues for the well owner.

In the case of flowlines and gathering lines, pigging can often be employed. In some instances though, pigging is either not an option or requires that parallel pipelines be installed. Other means of periodic cleaning of these lines have also been used, but the application of electrical heat tracing can significantly reduce or eliminate the need to pig flowlines.

V. Application of Heat

The addition of thermal energy to production systems not only enhances flow assurance, but also improves oil flow through the well and can result in significantly increased production rates.

The cooling of oil and gas as it flows from the reservoir up through the production tube to the wellhead is one of the first problems often encountered in difficult fields. Where gas-oil ratio is high, the wellstream temperature can drop significantly due to Joule-Thompson cooling effects of the expanding gas. In addition, heat loss through the well to the overburden (and to the sea for offshore cases) can further reduce the wellstream temperature. As it cools, viscosity can increase and wax can precipitate, restricting flow and reducing flow rates. Adding heat energy to the production tube counteracts these cooling effects. Figure 2 shows the temperature profile of an example well, both with and without heating.

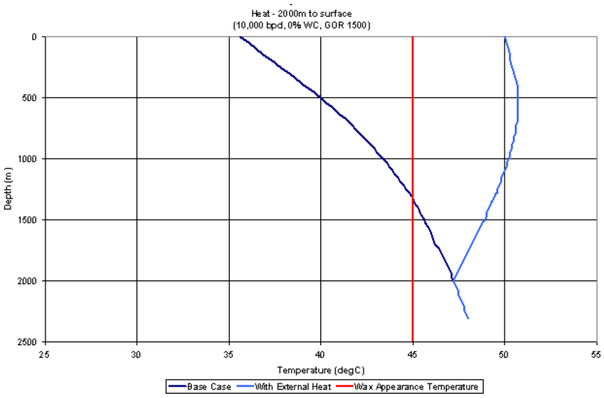

Figure 2: Simulation graph of oil temperature in flowing production tube

In many oilfields, the job is not yet done once oil reaches the wellhead. Pressure reduction at the wellhead and heat loss from valves and piping can cause further cooling of the wellstream. This is especially true for oilfields in cold climates. In addition, storage tanks may need heat management in order to keep stored oil from solidifying. Thermal insulation and the application of heating systems to the surface equipment can provide an effective solution to these problems.

VI. Heat management flow assurance methods

Insulated wells

In some cases, it may be sufficient to construct the well such that it incorporates a gas filled annulus, insulating gels or insulating cements to reduce wellbore heat loss. While insulated wells have a high capital cost associated with them, they incur no additional energy cost once installed.

Downhole heating

Simulation studies on the thermal behavior of oil as it flows through the production well have been used for a number of years. These studies show the temperature profile as the oil flows towards the surface. Often these studies are used to determine the amount of heat required to prevent excessive cooling, and the depth to which the heating must reach.

For the example shown in Figure 2 a heating system is required that will apply heat starting 2000m below the wellhead. This can be accomplished using electric heat tracing applied to the external surface of the production tube, or by installing a coiled tube based electric heater inside the production tube (directly in the wellstream fluid). Figure 3 illustrates a heater applied to the external surface of the production tube.

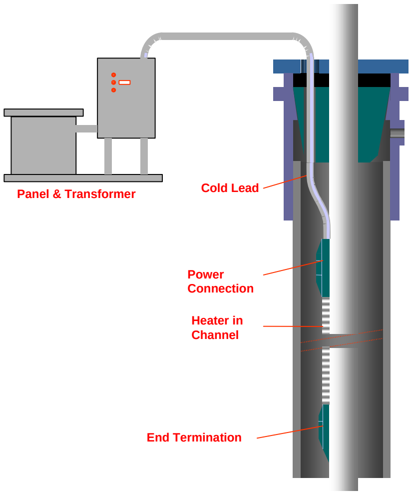

Figure 3: Conceptual configuration of wellbore heating system

Wellhead insulation and heating

The first line of defense for heat management on surface equipment is thermal insulation. A variety of insulations are readily available for this purpose, but when heating is required some insulations are more suitable than others. A discussion of thermal insulations appears later in this paper.

Wellhead heating may consist of tree heating, platform equipment and pipe heating, and bulk heating of the oil prior to pumping it into pipelines. Steam, hot water, hot oil and electric heating are commonly used in wellhead heating applications. The complexity and cost of infrastructure to use hot fluids and steam has resulted in increased interest in electrical heating for wellhead applications.

Gathering and Transfer line heating

Insulation and heating are common for onshore gathering and transfer pipelines (see Figure 4). Insulation has been in use for some years on subsea flowlines to reduce heat loss. Hot fluids, steam and electric heat tracing have all been used onshore, but the current trend for offshore flowline heating is toward electric heating systems.

Figure 4: Onshore heat traced pipeline

VII. Thermal insulation systems for offshore pipelines

Micro-porous insulation

Micro-porous insulations utilize a steel pipe-in-pipe configuration and special insulation in order to obtain very good thermal efficiency. These systems typically require that each prefabricated length of pipe be sealed, with a partial vacuum drawn down in the insulation annulus. The annulus may further be filled with an inert gas (at reduced pressure). Depending on the level of vacuum maintained and the gas type in the annulus, thermal conductivity (K-factor) can range from 0.0011 to 0.017 W/(m·K).

Polyurethane foam

Low density polyurethane foam (PUF) insulation has been used for decades to insulate onshore piping systems and has seen use in subsea applications as well. The foam provides a low K-factor, normally in the range of 0.020 to 0.030 W/(m·K), making this the second most thermally efficient insulation currently in use for subsea piping. PUF is a relatively inexpensive material, although it is necessary to provide an outer casing adequate to isolate the insulation from the external water pressure.

Syntactic insulations

Syntactic insulations incorporate tiny gas-filled glass bubbles into epoxy or polymer binding compounds to yield a composite insulation system, providing good mechanical properties but relatively poor thermal conductivity – typically an order of magnitude worse than micro-porous and PUF insulations. A major advantage of syntactic insulations is their strength, reducing the need to provide external mechanical protection as is required by other types of insulation.

VIII. Thermal insulation materials for onshore pipelines

Calcium Silicate

Calcium Silicate has historically been used in high temperature applications due to its inherent rigidity and availability. Calcium silicate has a maximum temperature rating of 649ºC. However, Calcium Silicate is quite hygroscopic and has relatively low thermal efficiency, making it less desirable for many heat trace applications.

Expanded Perlite

Expanded perlite is similar to Calcium Silicate in terms of thermal conductivity. Perlite is rigid, non-hygroscopic (approximately 7% moisture absorbency), and has a high temperature capability similar to that of Calcium Silicate. These properties make it attractive for use on heat trace systems where high temperatures are expected and where mechanical strength is required.

Mineral Wool

Mineral wool fiber insulation has been used extensively with electric heat tracing due to the fact that it has 50% thermal efficiency improvement over calcium silicate, less than 1% moisture absorbency and very high temperature range of up to 450ºC.

Foam Glass

A significant characteristic of foam glass is that it is 100% non hygroscopic. Consequently, it is normally used where the insulation is expected to be frequently exposed to moisture and must be waterproof.

Polyurethane and Polyisocyanurate foams

PUF insulation is widely used for onshore pipelines, and is well suited for the temperature range typical of oilfield wellstreams. As in the case of polyurethane, polyisocyanurate foam is an efficient insulator, has good strength characteristics and low moisture absorption. In addition, polyisocyanurate has a somewhat higher temperature rating compared to polyurethane and exhibits good performance under moderately high temperature conditions.

IX. Thermal insulation for tanks

Thermally efficient, cost effective insulation systems are now available for storage tanks. These insulation systems have been designed to work well with external tank wall heat tracing and have become commonplace in refineries. They also work well with other forms of tank heating, such as internal hot fluid or steam coils, electrical immersion heaters, and heated recirculation lines.

Figure 5: Typical storage tank with vertical lock-seam insulation

X. Types of heating technologies

Both onshore and offshore oilfield equipment employ a number of heating technologies. A brief description of these heating systems is discussed in this section.

Hot fluid and steam

Hot fluid heating often utilizes waste hot water from process equipment, steam or recirculated heat transfer fluid. This method is often implemented as tracing, using small dimension tubes bundled onto the pipe. Hot fluid flows through the tubes, transferring heat to the flowline or equipment.

Direct heating with electricity

This form of electric heating, commonly known as impedance heating, has been used for many decades in pipe heating applications. In this type of heating, external connections to the pipe are made such that an electric current (typically AC) flows directly through the pipe wall itself, creating heat through joule and hysteresis heating effects. Since voltage isolation is a safety concern with this type of system, they are normally limited to short pipe lengths.

Impedance heating typically has an electric power factor between 0.6 and 0.7, so that power factor correction is often required when large systems are deployed. The efficiency of impedance heating is also somewhat lower than other forms of heating, since a significant amount of power is dissipated in the cabling which is typically external to the thermal insulation envelope of the piping.

Electric heating cables

A wide range of polymeric and mineral insulated (MI) heating cables are available for use heating pipelines, tanks and other equipment. For common oilfield applications, temperature regulating cables can be effective for heating trees and piping at the wellhead. MI heating cable is typically used where high power is required, or where the possibility of very high temperature exposure exists. Polymeric series resistance heaters can be used to heat longer piping segments and transfer lines. Heating cables have been applied to downhole and subsea heating as well as their more common surface piping applications.

Skin effect heating

Skin effect heating systems utilize a medium voltage wire inside of a carbon steel tube bundled to the flowline. Like heating cables, skin effect systems are very efficient since all of the heat is generated inside the pipe's thermal insulation envelope. The electrical power factor of skin effect systems is typically about 0.9, and normally does not require power factor correction.

The low impedance and high voltage capability of the skin effect heater enables it to operate over long circuit lengths at relatively high power. Pipelines of up to 20km can often be traced with a single circuit, minimizing power distribution costs. Skin effect heaters can also be used for downhole heating, and have been qualified for use in reeled flowline umbilicals.

XI. Integrated Oilfield Thermal solutions

The growth of oil and gas exploration has given an opportunity to evaluate and adopt new and emerging technologies and "bundle" some of these technologies into an integrated heat management solution. These solutions combine technologies such as state of the art modeling techniques, advanced fiber optic measurement technology, optimized heat application methodologies, and the versatility of the current generation of control systems to offer dependable, safe and economical flow assurance from reservoir to refinery. A typical heat management system is an engineered package consisting of well defined components that include system analysis, proven heat delivery sources (either electric or hot fluid), thermal insulation, and control and monitoring systems.

An integrated, optimized heat management approach for oilfields not only includes the basic components of a typical engineered heating system, but also adds state of the art thermal evaluation methods such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and wellstream simulation studies. Optimized thermal insulation methodologies can be applied, such as pre-insulated piping and lock-seam tank insulation systems. Sophisticated temperature control and monitoring systems can be designed using networked heat trace controllers and optical fiber distributed temperature monitoring systems. The integration of these components results in a safe, reliable and economic heat management system that enhances the performance of the oilfield.

Simulation studies and computational modeling

Sophisticated simulation and modeling techniques are used to model gas-oil flow inside the production tube and wellhead structure. In general, the focused component of these models is assumed to be the production tube that carries a mixture of oil and gas. These simulation studies offer insights into the flow and heat transfer distribution in the tubing and annulus section under various flow conditions.

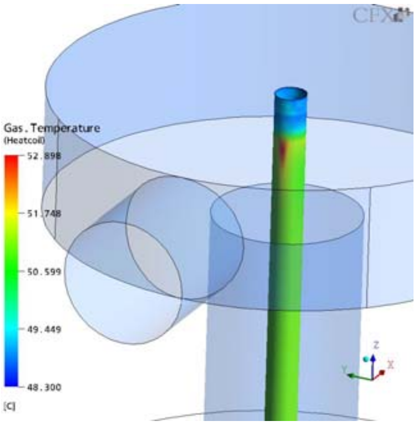

Figure 6: Wellhead flow CFD model

Finite Element and CFD analyses are carried out to establish the thermal profile and steady state conditions of the wellbore or pipeline. Two and three dimensional models can be built to represent a typical section of the system. The FEA and CFD techniques address in an exacting way problems such as non-uniform heat flux, providing insight into the temperature distribution of the product under steady state conditions.

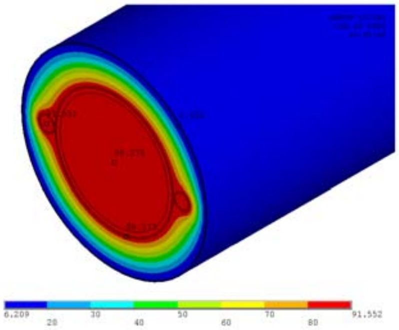

Figure 7: Thermal profile through heat traced pipe cross section

XII. Conclusions

An integrated heat management system combines products and technologies to offer significant advantages over the fragmented approach often practiced in the past. Integrating individual components into a seamless, efficient system produces positive results. Advancements in heating technology for downhole and subsea pipeline heating can be combined with proven thermal insulation methods to provide optimized flow assurance. Thermal insulation systems are selected to perform well in their environment, while ensuring optimum heater performance. An innovative, centralized control and monitoring system is chosen to provide real-time data, enabling accurate timely thermal intelligence on the entire oilfield.

The integrated heat management approach allows effective asset management, timely intervention and reduced down time that leads to significant cost savings, enhanced reliability and a higher degree of safety for oilfield applications.

VITA

Franco Chakkalakal received a BS degree in EE from Kerala University, India, a MS degree in EE from St. Lois University, St. Louis, MO and a MBA from DePaul University, Chicago, IL. Franco joined Chicago Bridge and Iron Company in 1972. Prior to joining Tyco Thermal Controls in 2001 as Global Product Manager for Skin effect heating technologies, he held several management positions in heat tracing industry, including the position of Chairman and Managing Director of a large heat-tracing operation in India, and Vice President of Engineering for another heat-tracing manufacturer based in the United States, responsible for Project, Product and System Engineering involving multinational projects. Franco was a member of the IEEE 844 working group that developed the industry standards for skin effect and impedance heating systems. He is a member of IEEE and ISA.

David Parman received a BS in electrical engineering from University of Akron, and an MBA from the University of Phoenix. David began his career in the electric heat tracing industry in 1978, and joined Raychem (subsequently acquired by Tyco) in 1996. David has been heavily involved with product development and product engineering for impedance and skin effect heating systems throughout his career. David was a member of the IEEE 844 working group for skin effect and impedance heating systems. He is a member of IEEE and ASME.