THERMAL EXPANSION IN ENCLOSED LINESHAFT PUMP COLUMNS

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INTRODUCTION

In a well pump handling hot water, when the pump is not in operation, those components above the static water level (SWL) are typically at a temperature substantially lower than when the pump is in operation. At start up the pump fills the column with hot water resulting in a lengthening of the column and shaft due to the thermal expansion. The difference in the change in length between the shaft and column resulting from the thermal expansion and other forces is a significant factor in pump design and selection.

In a vertical turbine pump, the shaft is attached to the driver (usually an electric motor) at the ground surface and to the impellers in the pump (or bowl assembly). Forces acting on the shaft tend to lengthen it when the pump is in operation. These forces, due to the weight of the shaft and the impellers, the thrust imposed by the impellers (when in operation) and the thermal expansion when the shaft is exposed to hot water all act in the downward direction. Since the shaft is suspended from the motor, the shaft tends to grow downward when these axial forces are exerted upon it. Though the shaft is supported in bearings attached to the column, it is free to move axially independently of the column. Vertical movement of the shaft manifests itself as vertical movement of the impellers within the bowls. Sufficient clearance (for vertical movement of the impellers) must be available in the housings to accommodate that portion of the thermal expansion and impeller thrust that occurs after pump start.

The impeller housings are attached to the pump column and together these components are suspended from the pump pedestal at the well head. As in the case of the shaft, the forces exerted by the weight of the column, the water in the column and thermal expansion, tend to cause the column to lengthen downward. This causes a movement of the impeller housings relative to the impellers (which are suspended on the shaft).

The thermal expansion resulting from the pump being submerged in hot water (the portion of the column and shaft below the water line) and the stretch of the shaft and column resulting from the weight of these components can be adjusted for and essentially "zeroed" at installation. When the pump is started and hot water fills that portion of the column above the static water level, additional change in length of the column and shaft occurs. This change in length in the column is due to thermal expansion for the most part but also due to the added weight of the water in the column as it fills with pump operation. Change in length of the shaft is due to thermal expansion and down thrust exerted by the impellers on the shaft. The net change in length between the shaft and column resulting from these forces, plus any allowance for manufacturing tolerances, is the clearance (lateral) required in bowl assembly.

In an open line shaft pump, with all components in the column exposed to the hot water directly, all of the forces tend to act at the same time as the pump is started thus resulting in a net length change calculation that is fairly simple. Consider the example of a pump producing 400 gpm of 190 °F water with a static water level of 360 ft. The pump is equipped with a 1 ½" stainless steel shaft and 6" column and the pump suction is located at 400 ft. Impeller thrust for this pump is 6.7 lb/ft of pump head. Once operating, the following changes in length would occur:

Shaft (impeller thrust) - 400 ft x 6.7 lb/ft = 2680 lb
Expansion of 1 ½" SS shaft at above load - 0.254 in

Shaft above SWL (thermal exp.) - 360 ft x 12 in/ft
x 0.0000055 in/in °F x (190 -100) = 2.14 in

Shaft below SWL (thermal exp.) 70 ft x 12 in/ft
x 0.0000055 in/in °F x (190-130) = 0.277 in

Column (due to added weight of water) - 360 ft
x 1.41 gal/ft x 8.3 lb/gal = 4213 lb
Expansion of 6 " column due to above load = 0.126 in

Column above SWL (thermal exp) - 360 ft x 12 in/in
x 0.0000063 in/in °F x (190 - 100) = 2.45 in

Column below SWL (thermal exp) 70 x 12 in/ft
x 0.0000063 in/in °F x (190 -130) = 0.318 in

Net expansion = (2.45 + 0.318 + 0.126) - (2.14 +
.277 + 0.254) = 0.233 in

The net expansion is small in this case (relative to the 0.75" standard and up to 1.375" machined lateral available in pumps of this size)and would be accommodated in most vertical turbine bowl assemblies. The key issue controlling the net expansion in this case is the fact that all of the change in length in shaft and column, particularly the thermal expansion, is occurring at the same time. In an open lineshaft pump this is the case since all of the components are directly exposed to the hot water.

In an enclosed lineshaft pump, the situation is quite different with respect to the thermal expansion occurring after the pump is in operation. In enclosed column assemblies, the shaft is located in the enclosing tube (Figure 1). This configuration protects the shaft from exposure to the

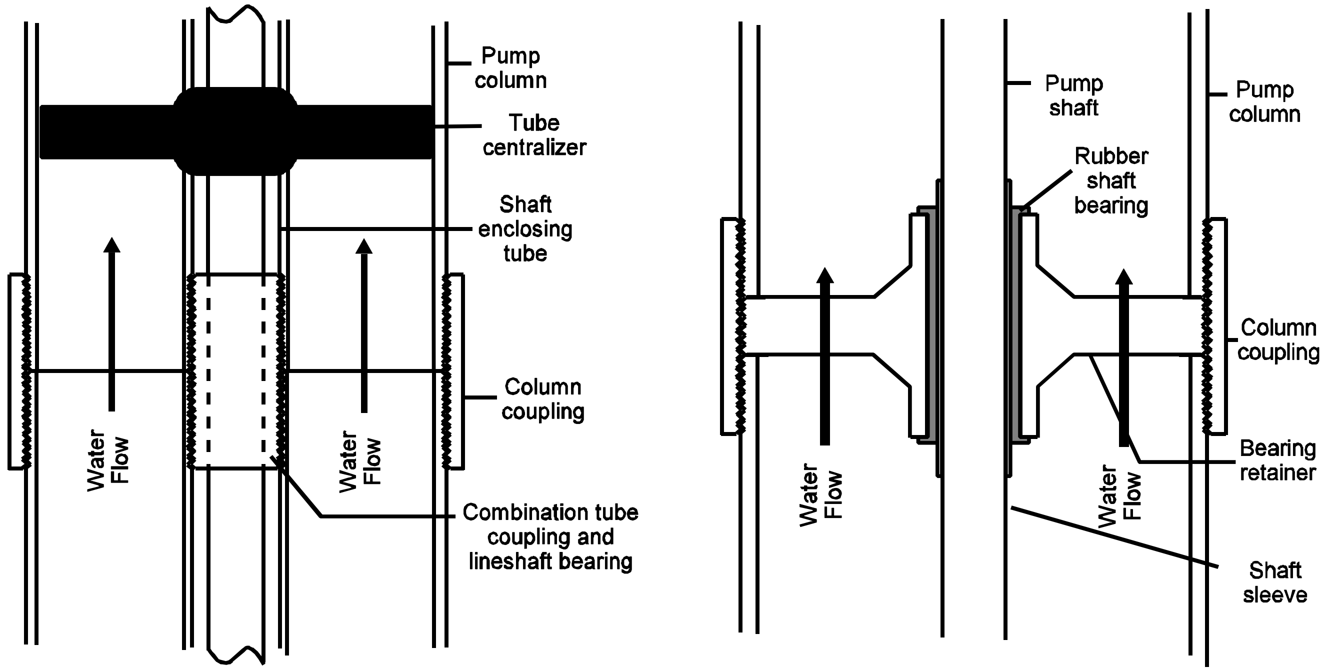

Figure 1. ***Details of lineshaft pump column types***

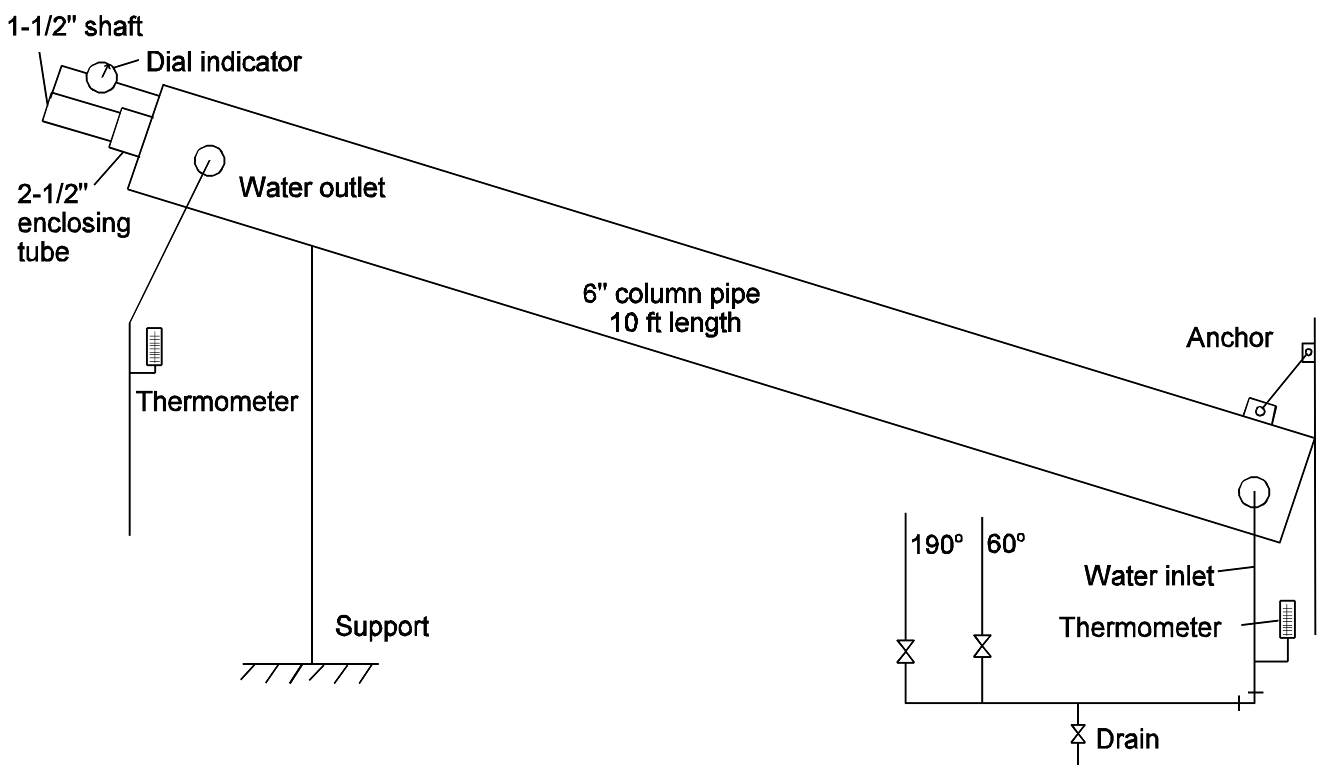

Figure 2. ***Diagram of experimental setup.***

geothermal water and allows the use of oil for bearing lubrication. At the same time, the location of the shaft (inside the enclosing tube) also "insulates" it from the water flowing up the column. At some point after the pump has been operating, the shaft does come to thermal equilibrium with the hot water - but at a much slower rate than does the column. This results in the column reaching it's full thermal expansion prior to the shaft. The unresolved question is - to what extent does the shaft lag the column in a typical application? Current treatment of this topic in one existing text (Culver and Rafferty, 1999) assumes that all of the column expansion occurs before any of the shaft expansion. This assumption results in the requirement for very large impeller-to-housing clearance (also sometimes referred to as lateral), essentially equal to the total gross thermal expansion (roughly 2.5" at the above example conditions). In most cases of static water levels of >150 ft and water temperatures of > 180ºF, a conservative calculation such as this would result in a required lateral in excess of that which could be accommodated with machining of the impeller housing.

Considering the situation from the opposite extreme, the assumption could be made that the shaft heats at the same rate as the column resulting in a zero net thermal expansion. Given the configuration of the column assembly, this seems an unlikely circumstance since the insulating effect of the air space between the ID of the enclosing tube and the shaft will undoubtedly result in some lag in the heat transfer to the shaft relative to the column. The importance of this lag in heating of the shaft relative to the column is that it translates directly into bowl assembly lateral requirements. Although the column and shaft, owing to their construction of similar materials (enclosed line shaft pumps typically employ a carbon steel shaft and column) may ultimately experience the same change in length due to thermal expansion, the rates at which the change occurs in the two components heavily influences lateral requirement in the pump. The maximum difference (relative expansion) in length that occurs between the rapidly expanding column and the more slowly expanding shaft contributes substantially to the lateral necessary in the bowl assembly for deep (> 150 ft)static water level applications.

TEST PROCEDURE

To evaluate this issue, a section of column was instrumented and configured in such a way as to allow the measurement of the maximum difference in thermal expansion between the column and shaft. The test apparatus is illustrated in Figures 2 and 3. It consists of a 10 foot section of 6 inch column equipped with a 2 ½ inch enclosing tube (5 ft bearing spacing) and a 1 ½ inch carbon steel shaft. The assembly was initially tested using 190ºF water from a geothermal system. Using a dial indicator to measure the differential expansion between the column and shaft, the results summarized in Figures 4 and 5 were obtained.

As indicated in the figure, the column reaches maximum thermal expansion at approximately 90 seconds after water flow is initiated. At that point, little if any thermal expansion has occurred in the shaft and this is the point of maximum relative expansion between the column and shaft

Figure 3. ***Experimental setup.***

Figure 4. ***Details of expansion measurement.***

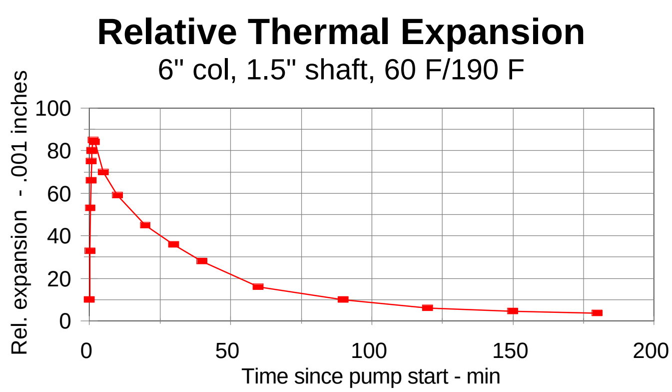

Figure 5. ***Relative thermal expansion.***

under the test conditions. After this point, heat transfer to the shaft results in it's slow change in length, gradually closing the difference in length to zero after some time of operation (approximately 2 to 3 hours in our test). Based only on this data, it would appear that the conservative calculation method mentioned above would be confirmed. However, this test was characterized by several parameters that tend to over estimate the relative expansion which occurs in an actual application. The initial temperature of the test section was equal to the room temperature (55º to 70ºF in our tests) - much lower than the 100 ºF average temperature of the air in the well above the static water level. More importantly, the temperature of the water passing through the test section, while equal to the production temperature of our wells was much higher than what would initially be experienced in service. In reality, the temperature of the water passing through the pump and column in the first few minutes of operation is substantially less than the temperature of the water produced after the well bore has reached thermal equilibrium. Due to the gradient that exists in the well under static conditions, much of the water in the well bore is less than the production zone temperature. As a result, the water produced initially is lower in temperature. The response of two of OIT's production wells is illustrated in Figure 6. Both of these wells produce approximately 193 ºF water after sustained production, yet the temperature of the water produced in the first 30 minutes after the wells have been out of production for some time is substantially lower.

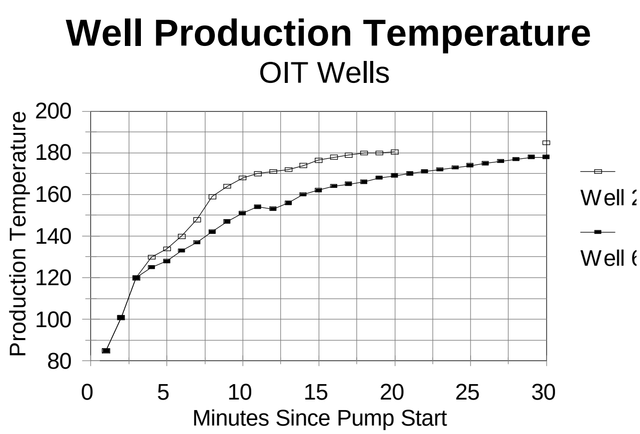

Figure 6. Well production temperature.

The curves indicate production temperature at the well head versus time since the pump was started. It is apparent that the two wells behave differently in terms of the temperatures produced and the time to reach thermal equilibrium. Though more data from other wells is necessary to confirm it, the difference may be related to the volume and surface area of the well bore. Well #2 is shallower (1288 ft, SWL 355 ft) and smaller in diameter than well #6 (1717 ft, SWL 360 ft). The relationship between the capacity of it's pump and the well volume (below the SWL) is such that the entire volume of the well can be produced by the pump in approximately 10 minutes. For well 6 this requires approximately 13 minutes. With the production zone in the bottom of both wells, the time required for the hottest water to reach the pump and the heat losses occurring between the water and the lower temperature casing between the pump and the bottom of the well result in an extended period before steady state is reached. The greater the well volume to pump capacity ratio the longer this "heat up" time will be.

RESULTS

To determine the impact of this initially lower temperature water, several additional runs were made on the test section with varying water temperature. Figure 7 presents the typical results of these tests.

These tests were run with exit water temperatures (from the test section) that mirrored those indicated in Figure 4. Adjustment of water temperature was less than optimum and excursions of up to 10 ºF from those in Figure 4 occurred in the course of the experiment. The test section was preheated to approximately 100ºF prior to each test to simulate the temperature of the air in the well above the static water level. It is apparent that the maximum relative expansion that occurs in an actual well capable of a steady state production of 190ºF water(as reflected in Figure 5) is much lower than that indicated in the initial test using 190ºF water .

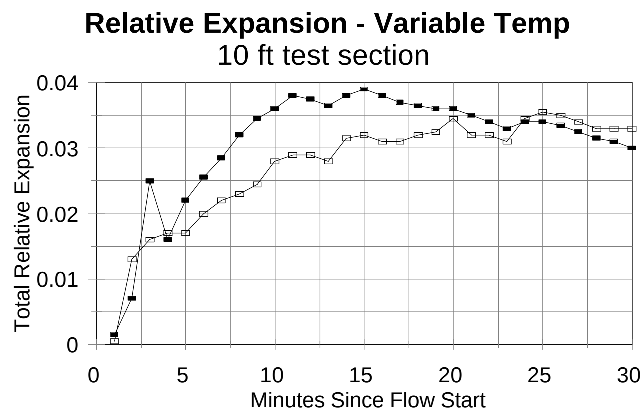

Figure 7. Relative expansion.

The maximum relative expansion of the 10-ft test section using the 190ºF water (and adjusting for a 100ºF pre test equilibrium temperature) is approximately 0.060 inches. Using the more realistic temperature response based on that measured in the OIT wells, the maximum relative expansion is reduced to the range of 0.033 to 0.038 or about 37 to 45% lower than the 190ºF test.. The slower rise in temperature of the water produced from the well effectively allows the shaft thermal expansion to "catch up" to the more rapidly expanding column, greatly reducing the lateral requirements in the bowl assembly. It may be possible to reduce lateral requirements further by slowly "ramping up" the well pump flow using a variable speed drive though this was not investigated in the work reported here.

Results of the testing of the 6-inch column equipped with a 1 ½-inch carbon steel shaft and 2 ½-inch enclosing tube confirm that approximately 90% of the thermal expansion in the column occurs before any of the expansion in the shaft when 190ºF water is flowed through the assembly. This results in a maximum relative expansion of approximately 0.006 in/ft of column for an initial temperature of 100ºF and a final temperature of 190ºF.

Using water temperatures reflective of the performance of the wells tested in this work, the maximum relative expansion was reduced to 0.0033 to 0.0039 in/ft of column for an initial temperature of 100°F and a final temperature of 190°F. The lower values was applicable to the initial temperature rise experienced in OIT well #6 and the higher value applicable to the temperature rise in OIT well #2 (see Figure 4)

CONCLUSIONS

Calculations found in the existing literature (Culver and Rafferty, 1999) regarding thermal expansion in enclosed lineshaft pump applications are largely correct with the exception of the consideration of the impact of well dynamics on the production temperature during initial start up.

The temperatures encountered by the well pump/column during the initial 30 minutes of operation are critical to the relative expansion that occurs between the shaft and the column. Well dynamics play an important role in the determination of these temperatures. Based on findings in the work reported here, the actual performance of the two wells measured indicates that the time to reach steady state temperature may be as much as 2 to 3 hours. The impact of this reduced temperature operation reduces the maximum relative thermal expansion in the example case by approximately 37 to 45% compared to that calculated using steady state production temperature.

For the bowl assemblies of the size considered in this test (nominal 9" bowl diameter), it appears that applications characterized by static water levels of less than 350 ft and steady state water temperatures of less than 190°F, can be specified with machining to achieve the lateral required. This is contingent upon the rate of increase in temperature of the water produced being limited to a maximum of approximately 2°F per minute for the first 30 minutes of operation. This may be achieved though the natural dynamics of the well or through speed control of the well pump. In some cases in which the well volume below the water line is very small relative to the pump capacity, it may not be possible to achieve this rate of increase.

The key parameters in the determination of the maximum relative thermal expansion are:

Static water level - determines the total length of column exposed to the maximum relative expansion. Deeper static levels result in greater lateral requirements.

Well production temperature increase rate - determines the maximum relative expansion. A pivotal parameter. Faster rates of increase result in greater lateral requirements.

Steady state production water temperature - determines the maximum temperature of system. Lower steady state production temperatures reduce relative expansion and total expansion.

Air temperature above the static water level - determines the initial temperature of the system. Higher air temperatures reduce the total expansion occurring in the system.

ADDITIONAL RESEARCH

A key finding of this work was the critical influence of the well production temperature rate of increase on the maximum relative expansion in the pump column. In the course of this work only two wells were available for data on this rate of increase. Due it's strong influence on the relative expansion, the collection of data from other wells would be valuable. In addition, more data from the two wells used in this work using gradually increasing flows at start up would also help to characterize the correlation between flow, temperature and well volume.

REFERENCES

Culver, G and K. Rafferty, 1998. "Chapter 9 - Well Pumps," *Geothermal Direct Use Engineering Design Guidebook*, Geo-Heat Center, Klamath Falls OR.