

TEMPERATURE MEASUREMENT AT LOW FLOW ON TYPICAL ANSI CHEMICAL PROCESS PUMPS

by

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ABSTRACT

Chemical process pumps can be required to handle highly temperature sensitive liquids. Improper operation of such a centrifugal pump can lead to potentially dangerous liquid temperatures within the pump casing. Determination of where and how to best monitor the liquid temperature inside a pump casing is the subject of this paper. This involves the determination of the points of maximum temperature generation and the relationship of this to measurements in other locations and by other methods.

This paper examines the actual testing performed on four typical chemical process pumps, of various manufacture, fitted with a multitude of temperature probes over the full flow range at various pump speeds. Extensive data are collected at deadhead (zero flowrate), examined, and compared with existing predictive published data.

INTRODUCTION

In a chemical process application with the potential for runaway polymerization, the measurement/control of the actual maximum product temperature is considered to be a process safety concern. It was recognized that low or no-flow conditions in a typical ANSI pump could potentially raise the product temperature above that necessary to initiate the polymerization reaction. The dilemma was that the batch operation required frequent switching, and any error created the real potential for deadhead operation.

This historically has been addressed in various ways, with mixed results. Consideration was given to the installation of power monitors, flowmeters, and bulk process temperature probes to protect against deadhead operation. However, these presented several additional issues. The lack of sensitivity and maintainability, as well as the propensity of the process fluid to polymerize on and around protrusions into the flowpath, made these common methods unpopular for stand-alone pump/process protection.

Since temperature is actually the parameter of primary concern, it seemed logical to develop a method to measure it as close to the source of heat addition as possible (at the pump). Then the question had to be asked, "Where on, in, or around the pump is the maximum temperature generated, and where and how can this be best measured?" A literature search did not turn up any specific information and, due to the importance of being sure, it was determined that testing should be conducted. Representative pumps were set aside to be instrumented and tested to find the "hot spots" and what was the most practical way to measure these. This information would be used to predict when a process condition might start an unwanted chemical reaction inside the pump.

Determination of the optimum location for measurement of the maximum temperature generated in the pump and the relationship of other locations allows the selection of an optimum measurement location and the determination of its time response in relation to the maximum temperature. This relationship enables the application of a safety margin to assure that the critical process temperature is not reached at any point. This information can be used to provide reliable protection of the system while furnishing positive operator feedback to reinforce good operating practices and maximize system reliability.

The further examination of these test results also allows reasonable (rule-of-thumb) prediction of temperature rise across ANSI pumps at various low flowrates, speeds, and horsepower levels. This information can be useful to ANSI pump users in applications similar to those tested.

TEST OBJECTIVES AND PROCEDURE

A total of five ANSI centrifugal pumps were tested using water as the test fluid. Three open face impeller pumps (1×1½-8 If, 1×2-10, and 2×3-13) and two reverse vane impeller pumps (1×2-10 and 2×3-13) were tested.

The objective of this test was to find the location on or around the pump to sense the highest temperature rise during low flow and no-flow or shutoff conditions. Secondly, we were to determine the most practical and reliable means and locations for these measurements. If a means could be developed to predict the temperature rise and rate from the data, this would also be helpful.

There were three different styles of thermocouple sensors that were used to measure the temperature of the fluid. All three types of sensors were mounted at various locations on the front casing, backplate, seal chamber, suction piping, and discharge piping of each pump tested. The three sensors evaluated were:

- Iron-Constantan type J grounded thermocouples, 1/8 inch diameter, were immersed inside the fluid through holes that were drilled and tapped in the pump casing. These sensors are identified by the prefix "P" in front of the number to indicate that these sensors penetrate the pump-casing wall. (Refer to Figures A-1, A-2, and A-3.)
- Bayonet style, Iron-Constantan type J thermocouples were mounted in direct contact with the pump wall material. The pump casing was drilled and tapped according to the manufacturer's recommendation, and the sensor installed in the hole and utilizing spring to force direct contact with the pump case wall. (Refer to Figure A-1.) (These quickly proved the least responsive, and were abandoned midway through the testing.)
- Surface mounted Iron-Constantan type J thermocouples were attached to the surface of the pump casing and piping by using epoxy glue. This sensor was identified by the "S" prefix in front of

the number to indicate that it is mounted on the surface of the pump or piping. (Refer to Figure A-1.)

In general, the test procedure was to run the pump through its full head capacity (H-Q) curve while measuring the temperature at various locations on the pump. After these data were gathered, the pumps were then operated at low flows (usually 20, 10, and 5 gpm), then the discharge valve was slowly closed until the pump was operating at no-flow or shutoff. In addition to the temperatures, the flowrate, head, power, and torque transmitted were also monitored during these tests.

After several tests, the highest temperature and quickest response was seen by the through-wall thermocouples (P sensors). The location of the most responsive sensor, however, was different for pumps with different style impellers. The pumps with an open impeller had the best temperature response on the front casing of the pump. Pumps with reverse vane impellers had the best temperature response on the backplate of the pump. The bar chart in Figure 1 shows the comparison of sensor temperature response during the tests. The bar chart represents the sensors with the greatest number of tests in which a specific sensor had the highest temperature and quickest response. These are the thermocouple locations that could be most productively monitored (with either surface mounted or through-wall thermocouples), and give the most accurate measurement of the liquid temperature inside the pump.

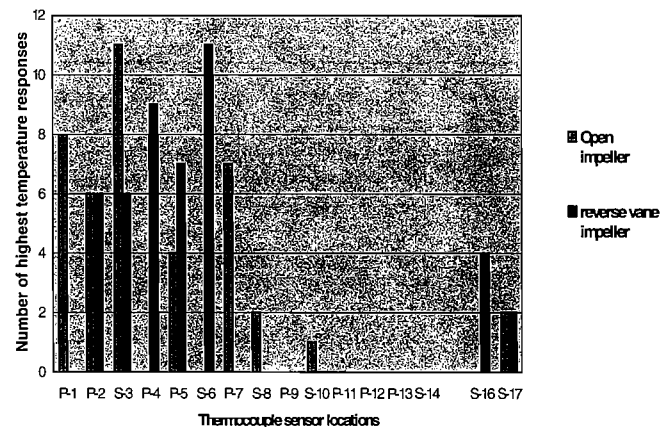


Figure 1. Sensor Response with Open and Reverse Vane Impellers.

Specific sensor locations and nomenclature used throughout the paper are identified in APPENDIX A. In APPENDIX A, you will also find Figures A-1, A-2, and A-3, which show the location of several sensors.

Figure 1 shows that the highest and quickest temperature responses for open face impellers can be seen most consistently with the P-1, P-2, P-7, and S-3 sensors. Therefore, the most accurate locations to indicate the temperature rise would be to install sensors on the front casing of the pumps with open impellers.

Figure 1 also shows that the highest and quickest temperature responses for reverse vane impellers can be seen most consistently with the P-4, P-5, and S-6 sensors. Therefore, the most accurate location to indicate the temperature rise would be to place sensors on the backplate of the pumps with reverse vane impellers. Note that the case mounted through-wall sensors (P sensors) were very close in temperature rise as well as maximum temperatures seen. Also note, that the surface mounted sensor on the suction piping (S-17) had a strong correlation to the liquid temperature at shutoff. This sensor could be monitored for sensing shutoff operation.

The maximum sensor responses in different manufacturers' pumps can be largely attributed to the way each manufacturer locates their impeller inside the pump casing.

- *Open impeller* pumps have their clearance set against the front casing. This is the area of the pump that has the quickest and highest temperature response.

- *Reverse vane impeller pumps* have their clearance set between the backplate and the impeller. Therefore, the backplate areas of these pumps have the highest and quickest temperature response.

One probable explanation for the differing “hot-spot” locations is that the increased shearing action, between the impeller and the pump casing (in the location where the clearance is set), inputs the most energy locally. These clearance areas have the thinnest liquid boundary layer and highest liquid shearing action. This additional energy input creates the higher temperatures in that specific area of the pump casing. These same areas also exhibited the highest surface temperatures on the outside of the pump casings. Note that the volume of liquid inside these ANSI pumps is very small. It varied from 0.44 to 1.0 gallon. The small quantity of liquid inside the pumps allowed the temperature rise of the circulating liquid volume to occur faster than could be transferred through the metallic mass of the pump casing.

TESTING RESULTS

The actual temperature rise at low flowrates was measured at three different speeds (however, for brevity only two will be individually shown). The following presentation discusses the data, their interpretation, and practical uses.

Temperature Rise at 1800 RPM at 10, 5, with 0 GPM

Figure 2 shows that the temperature at 10 gpm is close to 80°F. When the discharge valve was closed until the flow was 5 gpm, the temperature increased over several minutes approximately 5°F. Then the discharge valve was closed and the pump ran at shutoff. The surface mounted sensors and the sensors immersed in the liquid have slopes that are similar. This type of temperature rise/response is very consistent with the other pumps tested. On the 1800 rpm pumps, the temperature rise is relatively slow and measured 6°F per minute for each minute of operation at shutoff or dead head.

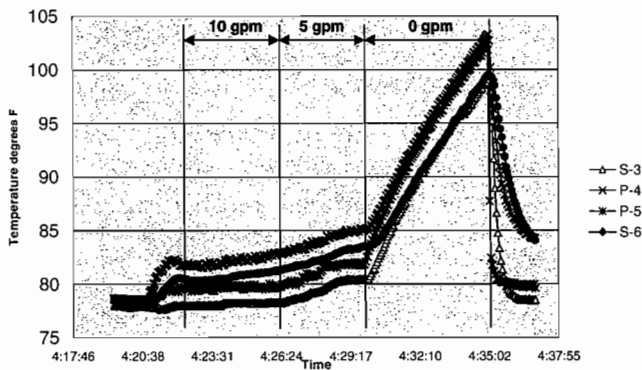


Figure 2. Temperature Rise at 1800 RPM with 10, 5, and 0 GPM.

Temperature Rise at 3600 RPM, at 10, 5, with 0 GPM

Figure 3 shows that the rate of temperature rise at 3600 rpm is much greater than the temperature rise found in the 1800 rpm cases. This temperature rise was approximately 64°F per minute.

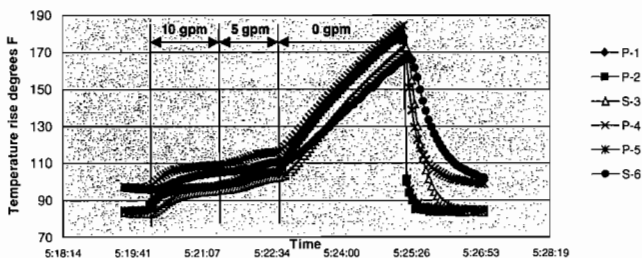


Figure 3. Temperature Rise at 3600 RPM with 10, 5, and 0 GPM.

Temperature Rise at 1800 RPM with 0 GPM

Figure 4 shows that the sensors in the liquid (P sensors) and the surface mounted sensors (S sensors) have a very similar temperature rise. The slopes of these response curves are close to being the same. The temperature rise or slope is 6°F per minute. The similar temperature response is likely due to the longer time it takes for the 1800 rpm pumps to heat the volume of liquid in the pump, allowing time to heat the pump casing.

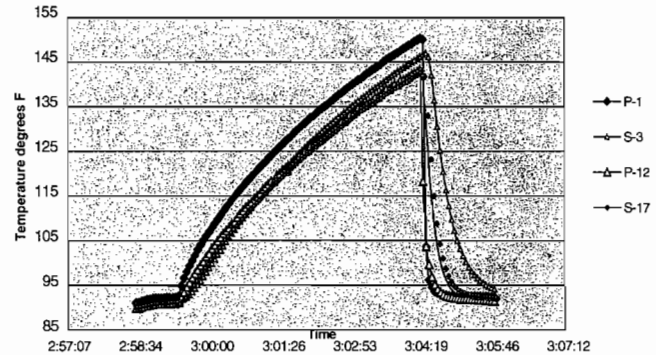


Figure 4. Temperature Rise at 1800 RPM with 0 GPM.

Temperature Rise and Fall of Two Tests at 3600 RPM with 50 to 0 GPM

Figure 5 shows that the sensors in the liquid (P sensors) and the surface mounted sensors (S) diverge more than the 1800 rpm cases. The temperature rise per minute for the 3600 rpm case is 64°F. The divergence between the through-wall and surface mounted sensor response is due to the thermal lag on the exterior of the pump casing. During this test, the fluid temperature rise occurred in such a short time that the test was conducted twice to verify the first results. The data are almost identical.

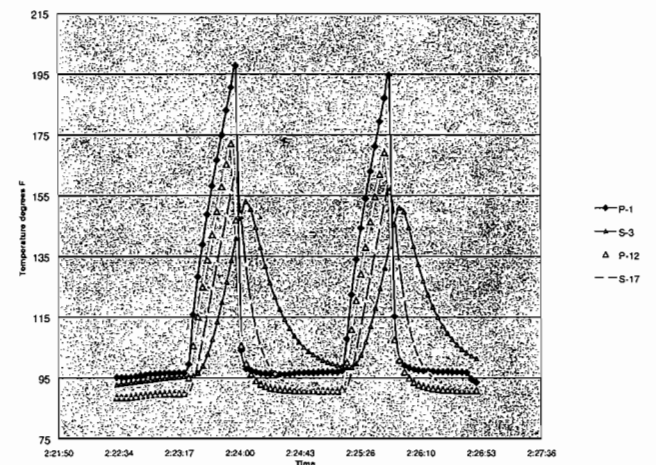


Figure 5. Temperature Rise and Fall of Two Tests at 3600 RPM with 50 to 0 GPM.

In most cases, the temperature rise at flows less than the manufacturer’s recommended minimum flows did not increase much more than 5°F to 10°F, and this temperature increase did not occur until the flowrate was in the 20 gpm range.

In general, the average temperature rise at 1800 rpm was approximately 6°F per minute, the 2900 rpm temperature rise was approximately 42°F per minute, and the 3600 rpm temperature rise was 64°F per minute. During the low speed (1800 rpm) testing at shutoff, the temperature rise was slow enough for the through-wall and surface mounted sensors to have similar temperature rises.

However, during the higher speed (2900 and 3600 rpm) testing at shutoff conditions, the through-wall sensors responded much quicker than the surface mounted sensors. This divergence in temperature response between the surface mounted sensor and the through-wall sensors was apparently due to the rate of temperature rise. This divergence was measured and can be predicted, knowing the pump speed.

The use of nonintrusive temperature sensors (desirable for process containment reasons) requires the evaluation of the divergence of their indication from the actual maximum temperature. This was done by comparing the various data, determining the divergence, and thus the “safety margin” required.

Safety Margin for 1800 RPM, 2900 RPM, and 3600 RPM

Figure 6 compares the pump required safety margin to the pump speed, and shows that at 1800, 2900, and 3600 rpm the measured temperature rise per minute is dependent on which of the two different types of thermocouple sensors is used. We have defined this divergence as the *safety margin*, which is the difference between the highest temperature rise measured by the through-wall (P sensor) and lowest temperature rise on the surface mounted sensors (S sensor). Note that as the pump speed increases, so does the divergence of temperature indications and therefore the “safety margin.” In other words, if a surface mounted sensor was used, the expected error in transient temperature indication (the “safety margin”) would be compensated for as a lowering of the permissible surface mounted temperature indication.

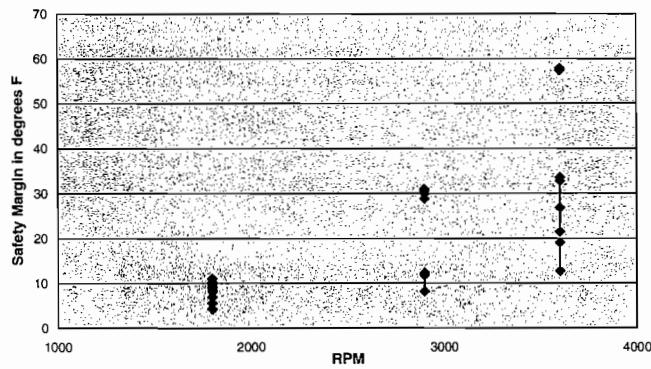


Figure 6. Safety Margin for 1800 RPM, 2900 RPM, and 3600 RPM.

After comparing the data of the 31 pump tests, the authors find (as expected) that the rate of the temperature rise is much higher for the higher horsepower pumps. The data clearly indicate that as the shutoff horsepower increases, the temperature rise will also increase, as seen in the graphs below.

The Temperature Rise Compared with the Shutoff Horsepower at 1800 RPM

Figure 7 shows the relationship between the temperature rise per minute and the shutoff horsepower for both types of impellers tested. This information is a compilation of all the pumps tested at 1800 rpm. The temperature rise equation or the graph can be used to estimate the liquid temperature rise per minute inside the pump, if the shutoff horsepower is known.

The Temperature Rise Compared with the Shutoff Horsepower at 3600 RPM

Figure 8 shows the relationship between the temperature rise per minute and the shutoff horsepower for both types of impellers tested. This information is a compilation of all the pumps tested at 3600 rpm. The temperature rise equation or the graph can be used to estimate the liquid temperature rise per minute inside the pump, if the shutoff horsepower is known.

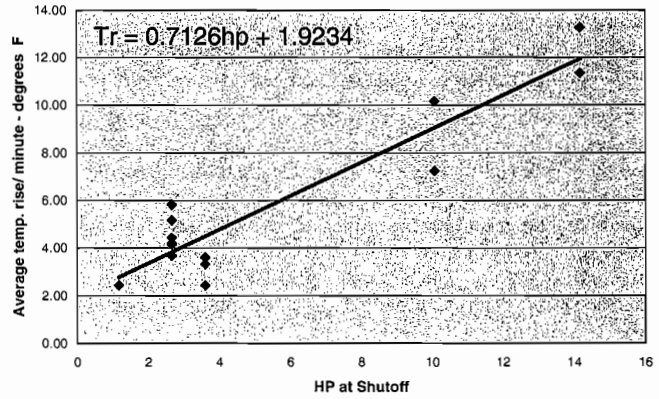


Figure 7. The Temperature Rise Compared with the Shutoff Horsepower at 1800 RPM.

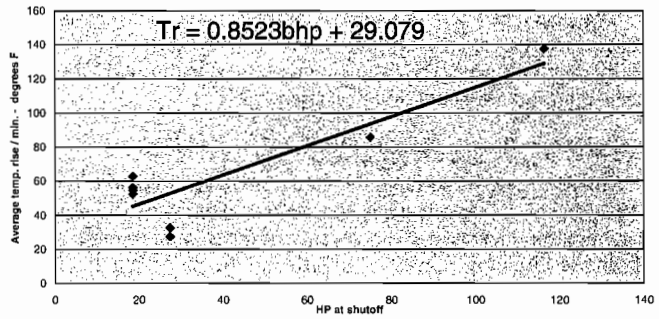


Figure 8. The Temperature Rise Compared with the Shutoff Horsepower at 3600 RPM.

It was considered important to try to develop a practical means of predicting the rate of temperature rise for ANSI pumps at shutoff for future work. Therefore, the authors tried to correlate and compare the empirical relationships in the data they had collected.

Comparison of the Temperature Rise Measured by the P and S Sensors Versus Shutoff Horsepower for All RPM

Figure 9 shows the average temperature rise measured by the through-wall and surface mounted sensors compared with the horsepower at shutoff. Notice that the temperature rise increases with shutoff horsepower as expected. These temperature rise equations can be used to estimate the temperature rise of the liquid at shutoff, if the shutoff horsepower is known. APPENDIX C provides a tabular summary of the pump tests comparing and averaging open and reverse vane impeller pump’s temperature rise per horsepower while grouped by rpm and sensor type.

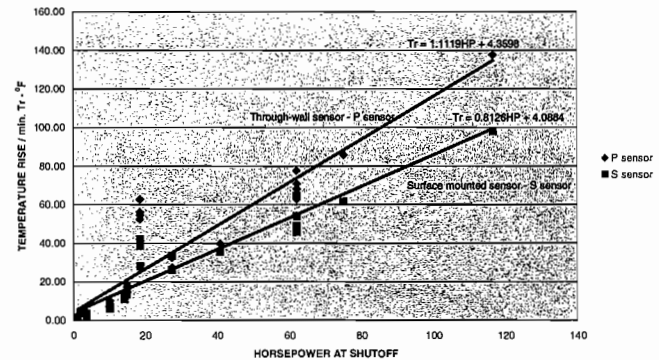


Figure 9. Comparison of the Temperature Rise Measured by the P and S Sensors Versus Shutoff Horsepower for All RPM.

Comparison of Actual Measured Temperature Rise and Calculated Rise Versus Shutoff Horsepower for All RPM

Figure 10 shows the correlation between the actual temperature rise and the calculated temperature rise using the total operational pump weights (pump and contained liquid). This is a reasonable correlation (especially considering the many things that can influence the data obtained), but tells nothing of where or how best to measure this temperature.

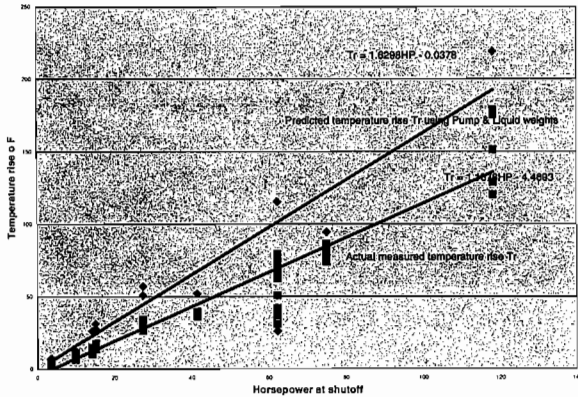


Figure 10. Comparison of Actual Measured Temperature Rise and Calculated Rise Versus Shutoff Horsepower for All RPM.

In searching the literature on this subject, the authors found a Hydraulic Institute calculation (1994) for the prediction of the temperature rise in a pump at shutoff. They compared the values obtained from this calculation with their data, but the correlation was disappointing. They then further tried to improve the correlation of that calculation and also developed an empirically derived mathematical description of their test results. These comparisons are described below.

- The HI equation (1994) temperature rise is calculated by:

$$Tr_{so} = (5.09 \times Ppso) / (V \times Cp \times s) \quad (1)$$

where:

- Tr_{so} is the rate of temperature rise at shutoff, °F/min
- 5.09 is a constant Btu-gal/hp-lb-min
- Ppso is input power at shutoff for the liquid pumped, hp
- V = casing capacity, gal
- Cp is specific heat, Btu/lb-°F
- s is specific gravity

- Empirical equation used to predicted temperature rise, based on weights and specific heats:

$$Tr = 42.2 \times (hp \text{ at shutoff}) / (Wp \times Cp + Ww \times Cw) \quad (2)$$

where:

- Tr is the temperature rise at shutoff, °F/min
- 42.4 is Btu/hp-min
- Wp is weight of the pump in pounds, casing, impeller, shaft
- Cp is specific heat of pump metal, Btu/°F
- Ww is the weight of the liquid in pump, lb
- Cw is the specific heat of the liquid, Btu/°F

The discrepancy between the predicted temperature rise and the actual measured temperature rise can be explained due to the fact that the Hydraulic Institute temperature rise calculation (1994) does not consider the effect of the heat loss into the casing, suction line, and the surroundings. It also does not consider the effect of the open suction line, which dissipated heat in the pump casing by mixing the hot liquid with the cooler liquid in the suction line. During all no-flow tests, the near-suction piping temperature increased with

the increased temperature inside the pump casing. During testing with higher horsepower pumps, the temperature rise in the suction piping could be seen further up the piping. Therefore, the Hydraulic Institute temperature rise calculation (1994) predicted much higher liquid temperatures than were actually measured.

The temperature rise equation, which considers the mass of the liquid and pump, predicted the temperature rise much closer to the actual measured temperature rise. This comparison can be seen in Figure 11.

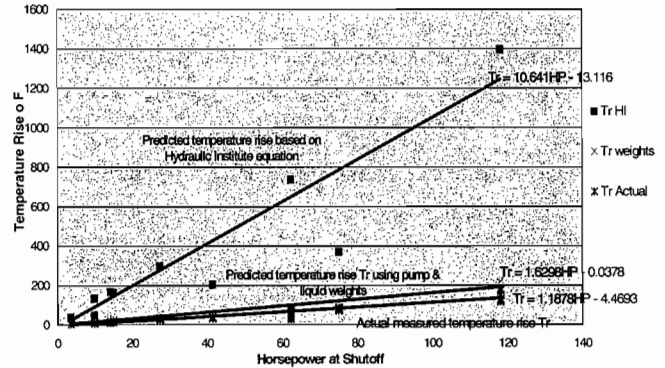


Figure 11. Comparison of the Actual Measured Temperature Rise Versus Hydraulic Institute and Weights Calculations.

Comparison of the Actual Measured Temperature Rise Versus Hydraulic Institute and Weights Calculations

Figure 11 gives the comparison of the predicted temperature rise based on the Hydraulic Institute equation (1994) and the actual rise observed. It also plots the predicted temperature rise using the combined pump and liquid weights (which has a much better correlation with the actual temperature rise).

CONCLUSIONS

These tests and graphs indicate that, with the determination of the “safety margin” for an application, a practical way to sense the no-flow temperature rise inside a pump is with insulated surface mounted thermocouples attached to the pump casing and suction piping. For ANSI pumps with open impellers, the thermocouples should be placed on the front surface of the pump casing at the 12 o’clock position and on the near-suction piping. For pumps with reverse vane impellers, the thermocouples should be placed on the backplate at the 12 o’clock position and near-suction piping. These surface mounted thermocouple sensors should have a safety margin applied to correct for the difference between the liquid temperature inside the pump casing and the surface temperature. APPENDIX B gives the suggested safety margins for the three different pump speeds tested.

Prediction of the temperature rise seemed to be most effectively done on an empirical basis (degrees per minute based on pump rpm) or calculated from the measured actual deadhead pump horsepower. The predicted temperature rise from the Hydraulic Institute equation (1994) and the total mass equation both overestimate the temperature rise. The Hydraulic Institute equation (1994) predicts much higher temperature rises than were actually measured. The equation that considers the mass and specific heats of the combined liquid and pump casing more accurately predicts the temperature rise at shutoff. However, neither of these equations accurately predicted the actual measured temperature rise. Other conclusions and observations are summarized as follows:

- The most accurate and responsive method to measure the actual temperature of the pumped fluid is with a thermocouple that penetrates the pump wall and is immersed in the pumped fluid.
- There seems to be enough circulation and turbulence of the pumped fluid to give a quick measure of changes in the average pumped fluid temperature.

- The point of highest temperature generation seems to be at the location of the pump that sets the clearance. Thus open impellers and reverse vane impellers generate the maximum temperature on opposite sides of the pump.
- While the seal chamber and seal seat are slightly warmer than the pump bulk temperature during normal operation, the rate of temperature rise in that area is much less than the bulk temperature during deadhead operation.
- The recirculation of fluid at the suction of the pump was more than expected during the tests, and resulted in the recommendation of the surface mount thermocouple at the pump suction to monitor for deadhead operation.
- Tests done at 1800 rpm indicate a relatively low rate of temperature rise, while those done at 2900 and 3600 rpm demonstrate dramatic increases in energy and temperature rise rate.
- Reasonably accurate measurements can be made external to the equipment, with the application of safety margins, to protect sensitive process fluids without compromising process containment. This can be done with maintenance and operations' friendly instrumentation that is easily integrated into existing distributed control system (DCS) controls.

APPENDIX A

Throughout this paper, the following legend is used to indicate the sensor locations. The following is a list of the sensors that correspond to the type of sensor being evaluated. The sensor locations are as identified below:

- P-1 Face of the pump case close to the inner diameter (ID) or eye of the casing at the 12 o'clock position
- P-2 Face of the pump case close to the outer diameter (OD) of the casing at the 12 o'clock position
- S-3 Surface mounted sensor between P-1 and P-2 sensors
- P-4 Backplate mounted at the 12 o'clock position close to the seal chamber
- P-5 Backplate mounted at the 12 o'clock position close to OD of pump
- S-6 Surface mounted sensor at the 12 o'clock position between P-4 and P-5
- P-7 On edge of the case volute at the 1 o'clock position
- S-8 Surface mounted at the 1 o'clock position next to P-7
- P-9 On edge of the case volute at the 2 o'clock position
- S-10 Surface mounted on the case volute at the 2 o'clock position next to P-9
- P-11 Discharge pipe below all valves
- P-12 Suction pipe close to suction flange
- P-13 Seal chamber
- S-14 Surface mounted sensor on the seal chamber
- S-16 Front of pump casing next to S-3 sensor
- S-17 Surface mounted sensor on the suction piping

Specific sensor locations are shown in Figures A-1, A-2, and A-3.

APPENDIX B

Table B-1 shows the suggested safety margins for the three different pump speeds tested.

How to use Table 1:

- For open face or reverse vane impellers operating at 1800 rpm and utilizing the surface mounted thermocouple sensors the liquid temperature can be predicted by following this example: If the

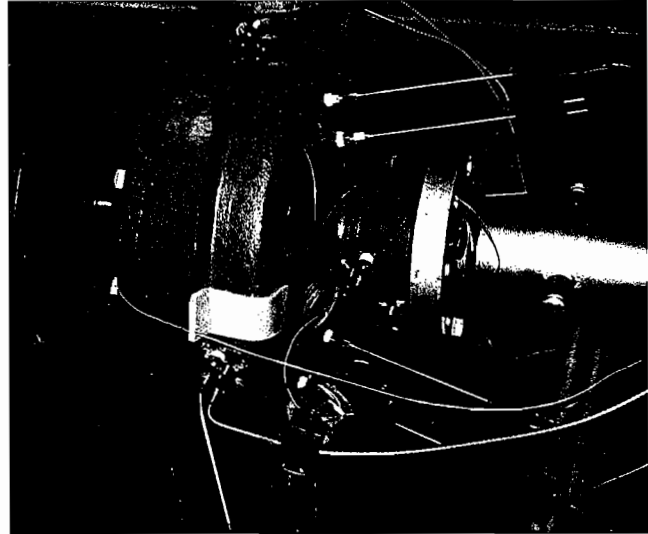


Figure A-1. The Location of Several Sensors and Types of Sensors.

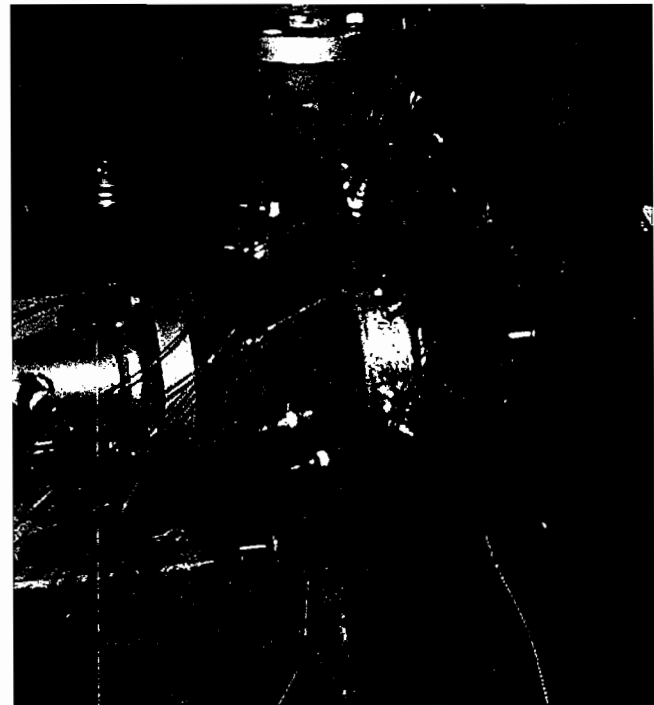


Figure A-2. View of the Sensors and Their Location.

Table B-1. Average Data Summary by RPM.

	RPM	Safety Margin Max P-Min S	Through-wall		Surface
			Tr / HP °F / minute	P sensor °F / minute	S sensor °F / minute
All 1800 rpm data Averages	1800	7.62	1.21	5.9	5.74
All 2900 rpm data Averages	2900	21.74	1.00	41.24	35.12
All 3600 rpm data Averages	3600	32.72	1.79	63.19	48.61

Safety margin is the Maximum Through-wall thermocouple (P sensor) temperature rise for that test minus the minimum temperature rise of the three quickest responding surface mounted thermocouple (S sensor).

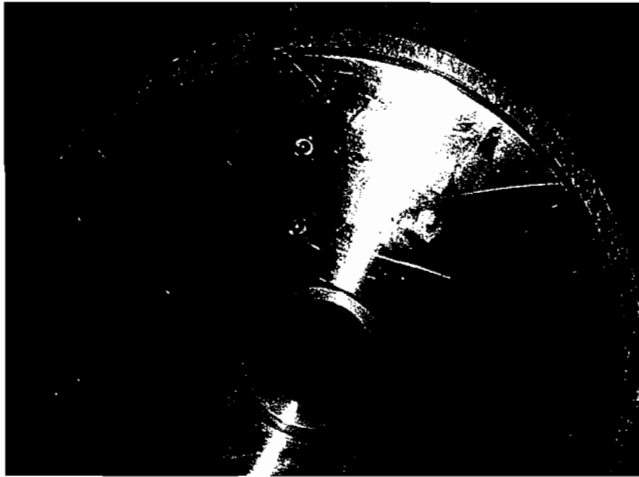


Figure A-3. A Typical Inside View of a Thermocouple Immersed Inside the Fluid. (These sensors were located in several places around the pump casing and backplate.)

liquid temperature inside the pump must not rise above 100°F, then the surface mounted thermocouple sensors should start the safety shutdown when the surface mounted sensor is reading 92.38°F (or 100°F – 7.62°F). The safety margin can be added to the surface mounted temperature reading to get the liquid temperature inside the pump casing.

- For pumps operating at 3600 rpm with a maximum liquid temperature of 100°F, the surface mounted sensor should be set to shut down when the surface mounted sensor is reading 67.28°F (100°F – 32.72°F).

APPENDIX C

Table C-1 shows a summary of pump no-flow data.

How to use Table C-1:

- If you have an open face impeller pump that operates at 1800 rpm, look under the open face impeller column and you will find that during no-flow or shutoff flow conditions the temperature of the liquid will rise at 5.26°F every minute the pump operates at no-flow. A surface mounted sensor will see a 4.41°F rise every minute it operates at no-flow. Another way to estimate the temperature rise is, if you have an open face impeller pump that has 10 hp at no-flow or shutoff conditions, then the liquid temperature rise inside the pump will be 15.7°F per minute (1.57 × 10 hp). If you use a surface mounted sensor, you will see 13.3°F (1.33 × 10 hp).
- If you have a reverse vane impeller pump that operates at 3600 rpm, then look under the reverse vane impeller column and you will find that during no-flow or shutoff conditions the temperature of the liquid inside the pump will rise at 65.86°F every minute that it operates at no-flow. A surface mounted sensor will see a 52.28°F rise every minute that the pump is operated at no-flow. If the pump is rated at 50 hp at no-flow conditions, then the liquid inside the pump will rise at 56°F per minute (1.12 × 50 hp). If you use a surface mounted sensor, you will see 50.5°F (1.01 × 50 hp).

The third column is the average of these two columns.

APPENDIX D

- Thermocouple accuracy ± 4°F or ± 0.75 percent, whichever is greater.

Table C-1. Summary of Pump No-Flow Test Data.

	Open Face Impellers	Reverse Vane Impellers	Average of Both Types
1800 rpm			
Temperature rise/min. – Tr °F Through-wall sensors – P	5.26	6.8	6.03
Temperature rise/min. – Tr °F Surface mounted sensors – S	4.41	6.64	5.53
Temperature rise / HP at shutoff Through-wall sensors – P	1.57	0.87	1.22
Temperature rise / HP at shutoff Surface mounted sensors – S	1.33	0.85	1.09
2900 rpm			
Temperature rise/min. – Tr °F Through-wall sensors – P	39.89	42.51	41.20
Temperature rise/min. – Tr °F Surface mounted sensors – S	35.49	34.16	34.83
Temperature rise / HP at shutoff Through-wall sensors – P	0.98	1.07	1.03
Temperature rise / HP at shutoff Surface mounted sensors – S	0.87	0.93	0.90
3600 rpm			
Temperature rise/min. – Tr °F Through-wall sensors – P	62.33	65.86	64.10
Temperature rise/min. – Tr °F Surface mounted sensors – S	39.58	52.28	45.93
Temperature rise / HP at shutoff Through-wall sensors – P	2.66	1.12	1.89
Temperature rise / HP at shutoff Surface mounted sensors – S	1.63	1.01	1.32

- The data acquisition accuracy is ± 1°F.
- The data acquisition instrument's resolution is 0.036°F.
- The response time of the through the wall thermocouple probes is 0.3 seconds using a grounded sheath style probe.
- The response time of a surface mount thermocouple probe is 0.3 seconds or better.
- Response time is defined as the time required to reach 63.2 percent of an instantaneous temperature change.

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