White Paper: McElroy Optimized Cooling™

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INTRODUCTION

HDPE piping systems deliver leak-free, long-lived infrastructure to many parts of the world. The pipe is available in numerous sizes and with varying resins and resin combinations. The pipe can be joined in numerous ways using a heat fusion process. McElroy Manufacturing leads the industry in designing and manufacturing heat fusion equipment for pipe sizes from ½” to 78” (50mm-2000mm) and has been making components and equipment for the polyethylene piping market since 1964.

This white paper presents McElroy Optimized Cooling™ for HDPE Fusion and highlights the benefits to contractors and project owners for following the optimized cooling process. This paper includes a brief history of the evolution of the butt fusion procedures widely employed today and summarizes the research and testing undertaken by McElroy in its search for an optimized solution. Finally, we provide an example project as a way to illustrate the time-savings that the Optimized Cooling allows and detail the process for customers and project owners to implement the Optimized Cooling into their operations.

A Brief History of Heat Fusion Procedures in North America

In 1994, The United States Department of Transportation (DOT) approached the Plastics Pipe Institute (PPI) for assistance in promoting uniformity in polyethylene joining procedures between various resin and pipe manufacturers providing gas piping products. PPI, in 1999, release Technical Report #33 (TR-33) which documents the testing done to develop and validate a generic butt fusion procedure for joining PE pipe. This Technical Report was a harmonizing and consensus-building project between the various pipe companies to identify the generic requirements which each company could approve for use across a wide range of possible job site conditions. In determining the generic requirements, PPI conducted significant research in order to establish the requirements for temperature and pressure. The testing was performed at limits beyond the harmonized values to validate the values used. The validation temperatures and pressures are shown as the dashed line in Figure 1 below. The final values used for the procedure are shown with the solid line in Figure 1 below.

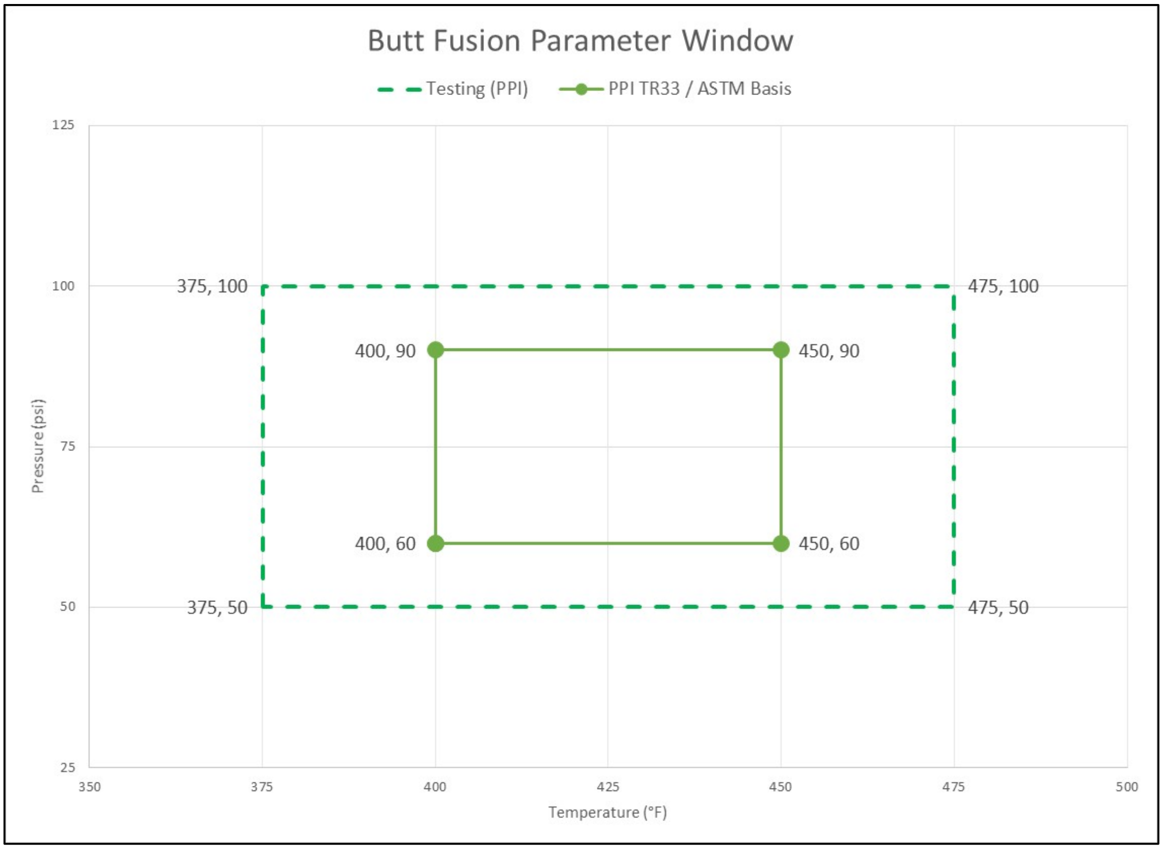

Figure 1

From this testing, PPI then led the effort to develop an ASTM standard related to PE pipe joining, and in 2006 the first version was released that included a pressure range within the larger TR-33 “window” and identified a cool time range of 30 to 90 seconds/inch of pipe diameter as specified in the TR-33 documentation.

In 2011, ASTM F2620-11 was published and changed the cool time under fusion pressure from 30-90 seconds per inch of pipe diameter to 11 minutes per inch of wall thickness. This better clarified the cool time required for pipes of all wall thicknesses and is easier to monitor.

For DR11 pipe (a very common choice at the time), The 11 minutes/inch of wall thickness EXACTLY matches a 60 seconds/inch of pipe diameter cooling time as shown in Figure 2 .

		TR33 Cooling			
IPS Pipe size	**OD**	**30s**	**60s**	**90s**	**ASTM F2620 DR11 Cooling Time**
1/2	0.84	0:00:15	0:00:30	0:00:45	0:00:30
3/4	1.05	0:00:22	0:00:45	0:01:07	0:00:45
1	1.32	0:00:30	0:01:00	0:01:30	0:01:00
1 1/4	1.66	0:00:37	0:01:15	0:01:52	0:01:15
1 1/2	1.9	0:00:45	0:01:30	0:02:15	0:01:30
2	2.37	0:01:00	0:02:00	0:03:00	0:02:00
4	4.5	0:02:00	0:04:00	0:06:00	0:04:00
6	6.63	0:03:00	0:06:00	0:09:00	0:06:00
8	8.63	0:04:00	0:08:00	0:12:00	0:08:00
10	10.75	0:05:00	0:10:00	0:15:00	0:10:00
12	12.75	0:06:00	0:12:00	0:18:00	0:12:00
14	14	0:07:00	0:14:00	0:21:00	0:14:00
16	16	0:08:00	0:16:00	0:24:00	0:16:00
18	18	0:09:00	0:18:00	0:27:00	0:18:00

Figure 2

Further, the calculated cooling time (ASTM F2620) for pipe diameters between DR9 and DR15.5 all fall within the 30 to 90 second range, as was determined in TR-33 initially. This range is shown in Figure 3.

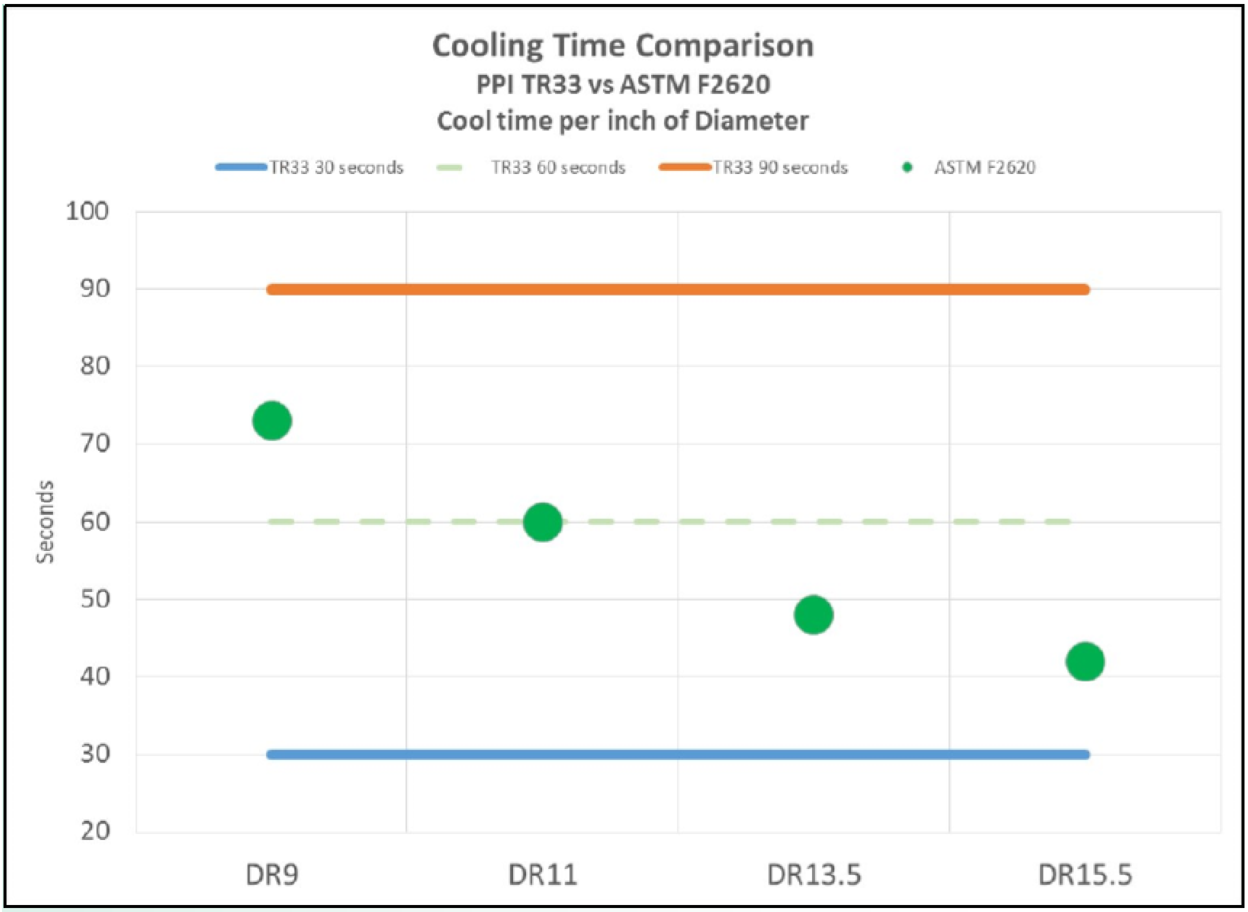

Figure 3

Although F2620 has been updated several times since the 2011 version, the cooling time under pressure of 11 minutes per inch of wall thickness has not been revisited. The value represents a harmonized solution – but McElroy asked the question: “Is it an optimized solution?”

Determining What Matters For Cooling

McElroy’s first impulse was to build something. We are a world-class design and manufacturing company and tackled the challenge of cooling time by embarking on the design of a new tool. In order to design a tool, we needed research, and for the better part of three years, McElroy has been researching and studying fusions – in different environments; with various pipe dimensions of diameter, DR, and density; and ranges of cooling times. Samples were fused according to F2620-13 (the current standard at the time the research was initiated) and cooled under pressure for various lengths of time. Samples were destructively tested, and McElroy’s research concluded that “the failure energy of the fusion joins remains constant whether cooled per the existing ASTM F2620-13 standard, reducing the fusion cooling time under pressure, or by altering the cooling rate based on ambient temperature conditions. (Hawkins, 2018).

The research focused on 18" diameter DR 7 (2.5 inch wall thickness) and DR 32.5 (0.55 inch wall thickness) PE4710. Hawkins and Ming sought to identify independent factors that affect cooling and quantify each variable's impact, determine core temperature at the center of the wall of the fusion joint at which fusion pressure may be released from the machine without negatively impacting joint strength, and quantify the impact to cooling time as a result of external methods of cooling.

Variables Considered

The research considered the following factors during the research into cooling:

- Heater temperature
- Heat soak time
- Interfacial pressure
- Cooling time under pressure
- Ambient temperature
- Pipe temperature[1]
- Pipe diameter
- Wall thickness of the pipe

Variables Held Constant Across Testing

- Heater temperature and heat soak time were held constant for all testing and in accordance with ASTM F2620-13.
- 75 psi interfacial pressure was used in the study

Variables to Study

ASTM F2620 advises that when working in high ambient temperatures increased cool time should be considered. The quantification of that increase is not specified in ASTM; thus, McElroy included three temperatures for its testing matrix: 40°F, 70°F, and 120°F. Each temperature was achieved in a temperature-controlled chamber with pipe sections and fusion equipment fully conditioned at the set point temperature prior to beginning the fusion process.

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[1] Pipe temperature considerations were studied subsequent to the 2018 publication.

Results

As expected, ambient conditions affect the cooling of the joint as shown in Figure 4 for the 18-inch DR7 case.

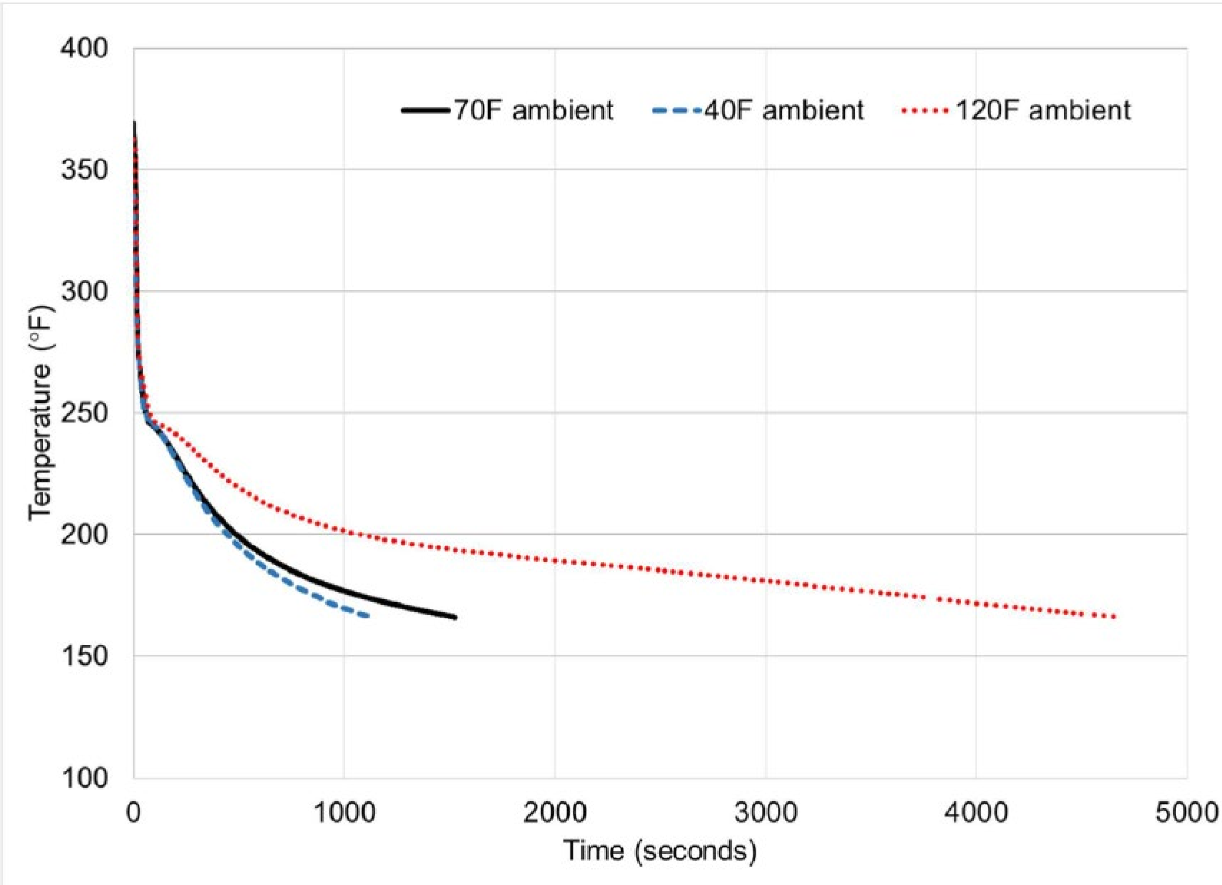

Figure 4

Initially following the butt fusion, the temperature in the joint decreases rapidly; after that point, however, the cooling slows significantly. The “elbow” in the curve is attributed to the recrystallization of the material as the polymer cools below the VICAT temperature. The research indicates cooling the center of the pipe to 200°F takes twice as long for the 120°F ambient case as for the 70°F ambient case, regardless of DR.[2]

Striplin (2010) studied cooling times as a function of interfacial pressure and ambient temperatures. His research confirmed the strength of the base pipe material at the temperature achieved by the cooling time specified in relevant fusion standards achieves approximately 50% of the final strength of the pipe when fully cooled to 73°F. After the initial elbow point shown above, the increase in strength becomes somewhat asymptotic with time. Said differently, a reduction in cooling time is not a linear reduction in strength of the joint at the time of its removal from the fusion machine. As is demonstrated by the

[2] Hawkins, page 8

hundreds of testing events[3] undertaken in this research, removing the joint from the machine after a shorter fusion/cooling period has minimal effect on the joint's final strength.

Striplin (2012) studied the effect of ambient temperatures on fusion cooling times, and Hawkin's (2018) research confirmed the earlier work showing higher ambient temperatures require longer time to cool.

Importantly, Hawkins' expanded research considered an additional temperature – the temperature of the pipe itself. Polyethylene pipe may sit in a yard or laydown area prior to being fused. Black pipe, especially, can be much warmer than the surrounding ambient conditions as polyethylene is an excellent insulator.

The culmination of research indicates the following parameters to consider in establishing a cooling time:

- Wall thickness (DR)
- Pipe Diameter
- Ambient temperature
- Pipe temperature

McElroy's research to date has included pipe sizes between 6 and 24" OD with DRs from 7 through 32.5. The data generated forms the basis for the Optimized Cooling algorithm.

This patent-pending process results in reductions of minimum cooling time under pressure up to 55% from the 11 minutes per inch of wall thickness stated in ASTM F2620-19. An example of this reduction is shown in the following example.

Optimized Cooling Impact To Productivity

Assume a 20" SDR 7 piping system being installed in West Texas: ambient condition ranging between 75°F and 120°F, and pipe temperature between 75°F and 140°F. The following table compares the cooling time required for completing each fusion.

Method	Ambient T (°F)	Pipe T (°F)	Minimum Fusion/ Cooling Time (s)	Reduction in Fusion/Cooling Time (%)
ASTM F2620-19	Not specified	Not Specified	1885	
F2620-19with McElroy Optimized Cooling™	75	75	849	55% reduction
F2620-19 with McElroy Optimized Cooling™	120	140	976	48% reduction

[3] Testing of all joints completed by both Striplin (2010, 2012) and Hawkins (2018) followed ASTM F2634 (2007 and 2015 versions, respectively).

As shown above, the McElroy Optimized Cooling™ algorithm reduces the minimum cooling time by 51% for the cooler scenario and 48% for the higher temperature example.

A ten-mile project would require 1,056 50-foot sticks of pipe. Using McElroy Optimized Cooling™, and assuming a 90°F average temperature, an operator could save roughly 250 machine hours from the reduced cooling time alone.

As introduced previously, the cooling time is dependent on ambient conditions, and ambient conditions – especially in west Texas – can change hourly. Thus, McElroy's Optimized Cooling™ requires the ambient temperature and pipe surface temperature for each joint. Thus, every joint – whether made first thing in the morning or in the middle of the day – will have cooling times consistent with the underlying algorithm and research.

Implementing McElroy Optimized Cooling™

Optimized cooling is only available for joining operations which utilize the DataLogger®6 or newer technologies. In preparing for a joint utilizing McElroy Optimized Cooling™ the operator inputs the ambient temperature, the surface temperature of the pipe to be joined, the DR of the pipe, pipe material, and pipe diameter. The DataLogger® then provides the graphical directions to the operator related to heat soak time (consistent with F2620) and the fusion/cooling time (as calculated). The joint records will then be stored in the Vault™ documenting the procedure used, the optimized cooling selected, and the data gathered during the joining process documenting the joint was completed in accordance with the optimized process.

Compliance with ASTM F2620-19

ASTM F2620-19 specifies cooling time of 11 minutes per inch of wall thickness. The practice also includes the following note:

> NOTE 10—Pouring water or applying wet cloths to the joint to reduce cooling time is not acceptable. Applying conditioned air is acceptable only as part of a controlled cooling cycle procedure where testing demonstrates that acceptable joints are produced using the controlled cooling cycle procedure.

The McElroy Optimized Cooling™ process was developed from years of testing that has demonstrated acceptable joints are produced and therefore meets the requirements of a "controlled cooling cycle procedure."

Compliance with Other Fusion Joining Procedures

McElroy Optimized Cooling™ is currently applicable to ASTM F2620. The Optimized Cooling algorithm has not yet been developed for other fusion methods used internationally such as DVS, GIS, WIS, ISO 21307 Low Single or ISO 21307 Dual Pressure.

Additional Considerations

The final strength of fusion joints is affected by how it is handled after removing the joint from the fusion machine. As is true for all fusions and as discussed in all fusion procedures, rough handling of the pipe is to be avoided until the joint has completely cooled (See ASTM F2620-19 Section 8.3.6)[4].

In completing the research referenced in this White Paper, Hawkins employed the following working definitions for normal handling and rough handling of pipe:

Normal Pipe Handling

- Elevating the pipe above the lower jaws of the machine with the pipe lifts fitted to the machine
- Pulling the pipe horizontally with support provided by pipe stands and/or rollers downstream from the machine per industry practice
- Lifting the pipe on both sides of the joint so that the joint is supported but the machine is able to be removed
- Using a pipe handling system that limits stresses to similar levels as the methods mentioned above.

Rough Pipe Handling (to be avoided)

- Lifting the pipe directly at the butt fusion thereby inducing bending stress directly on the joint [single-point lifting]
- Pulling the pipe horizontally out of the machine without adequate support and allowing the fused section to fall to the ground

Conclusions

Using ASTM F2620 fusion procedure, research spanning nearly a decade provides the basis and justification for optimizing the cooling time requirement for butt fusion joints as a function of pipe diameter, wall thickness, ambient temperature, and pipe surface temperature. The patent-pending McElroy Optimized Cooling™ procedure, when paired with trained operators, completed using properly-maintained and functioning equipment, and recorded via the DataLogger® and Vault™, provides significant time savings for butt fusions and ensures quality joints. As in all fusions, rough handling is to be avoided until the joint is fully cooled.

8.3.6 [4] ………. Avoid high stress such as pulling, installation or rough handling for an additional 30 min or more after removal from the fusion machine (only 10 minutes additional cooling time is required for IPS 1 in. and smaller pipe sizes). Do not apply internal pressure until the joint and surrounding material have reached ambient air temperature……

References

ASTM F2620-06

ASTM F2620-11

ASTM F2620-13

ASTM F2620-19

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