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What Is the Best Method for Preheating 4130?

A study compares three preheat methods based on time required, efficiency, safety, and cost

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In the oil and gas industry, AISI 4130 steel is a widely used material. This material is quenched and tempered for strength and other specific properties. Once the material has been welded, the properties of the heat-affected zone are adversely affected. In order to lessen the effects of welding on 4130, preheating is an essential requirement of the welding procedure. While the use of direct flame is the most prevalent, other commonly used methods include induction and resistance heating, with resistance being the next most commonly employed technique.

The purpose of this study is to compare induction, resistance, and direct flame preheating methods on multiple levels. This comparison is based on actual test data derived from preheating the same part with each method. No sales nomenclature or assumed data are used. The final result determined the most effective and efficient preheating method.

Methodology

A single valve body was chosen for the study because of its mass and its similar configuration to valves typically used in the oil and gas industry. The valve was preheated to an industry minimum of 500°F using typical industry practices for all three methods. Throughout each test, the temperatures on the inside and outside of the valve were monitored and recorded on a data recorder. The thermocouples used with the data recorder

remained in the same place for all three tests. Elapsed time was recorded in relation to power used and temperature readings. For each trial, once a temperature of 500°F was attained, the temperature was maintained for one hour and the energy used was recorded. Then, the temperature drop was recorded for one hour with no additional heat input. A Fluke® power meter was installed onto the primary input line just after the fuses at the wall disconnect to measure and record the active energy (in kilowatt-hours) used by the induction and resistance power sources. For the direct flame tests, propane fuel gas was used. The amount of propane consumed was determined using a scale to measure the before and after weight of the propane cylinder.

Test Procedures

Induction

The induction heater uses water-cooled cables to conduct high-frequency electric current to electromagnetically induce eddy currents within the material. The electromagnetic currents in the material cause the molecules to excite which generates the heat. As such, the heat is generated within the material compared to the other two methods where the heating sources are applied to the external surface and the heat must then be conducted through the part. This results in more uniform heating through the part

thickness and less radiated heat from the preheated component.

First, all valve surfaces were covered by wrapping the valve with an insulating ceramic fiber blanket. Next, an induction heating cable was wrapped around the valve over the blanket — Fig. 1. The cable was not in contact with the block at any point. Since the cables are water cooled they remain approximately at room temperature when properly insulated from the part. The induction heating machine uses thermocouples to monitor the temperature and control the machine's output. Two control thermocouples were placed on the valve, one on the inside and one on the outside, each within ¼ in. (6 mm) of the thermocouples used with the data recorder.

The induction heater controller was programmed to preheat the part to 500°F as quickly as possible, and then maintain that temperature for one hour. The data recorder was turned on, the power meter was set to record, and the induction machine was set to preheat. Both the data recorder and the power meter record time along with the other measurements. Once both thermocouples reached 500°F, the machine was set to maintain for one hour and the time on the data recorder and power meter were noted. After one hour, the machine was turned off and the temperature was recorded for another hour after making note of the time on the data recorder. Throughout the test, the amount of time required to set up and tear down was also recorded.

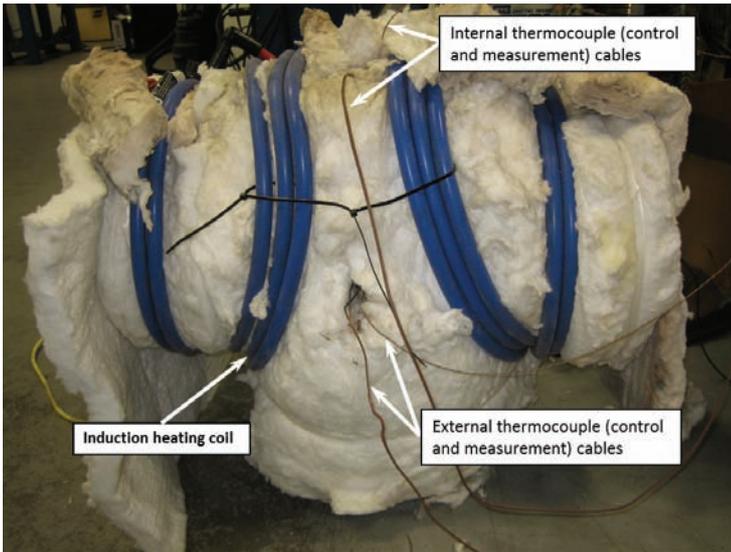


Fig. 1 — Position of induction heating coil, and measurement and control thermocouple cables.

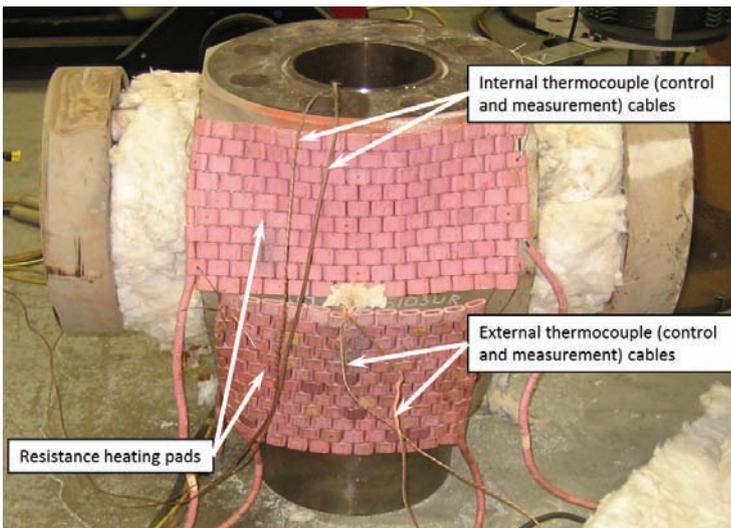


Fig. 2 — Placement of resistance heating pads and thermocouple cables.

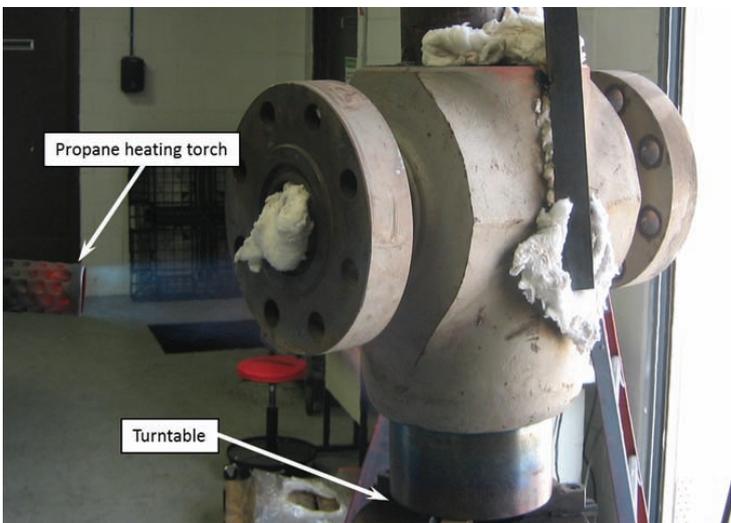


Fig. 3 — Direct flame preheating setup.

Resistance

The resistance heater uses resistance pads made up of a resistant element woven through ceramic tiles. This construction results in a heating pad with enough flexibility to allow for contouring the pad around or inside components with varying profiles. The element consists of a conductor having high resistance, so when electrically energized, the element heats up. The ceramic tiles both conduct this heat to the component as well as electrically insulate the heating element from the component. The heated tiles only transfer heat to the valve through radiant heat and conductive heat where the pads are in contact with the valve.

The resistance heating pads were first fastened to each other with wire and to the valve to keep them in place — Fig. 2. Next, the whole assembly was covered with an insulating ceramic fiber blanket. Two preheating zones (with separate control) were used with each zone using two resistance heating pads. The pads were arranged such that each of the two zones was on opposite sides of the valve.

The resistance heating controller uses one thermocouple per zone to monitor the temperature and control the output to that zone. Each zone had a thermocouple resistance spot welded onto the outside of the valve. The control thermocouple was connected to the valve within $\frac{1}{4}$ in. (6 mm) of the location for the measurement thermocouple. The second thermocouple was on the other side, on the outside of the valve. A thermocouple placed on the inside of the valve $\frac{1}{4}$ in. (6 mm) away from the one used for the data recorder was plugged into the machine for reference only.

The resistance machine was programmed to preheat the valve to 550°F as quickly as possible, and then maintain the temperature for one hour. A previous test showed that when setting the machine to preheat to 500°F, it required more than six hours for the inside to reach 500°F after the outside had attained this temperature, so programming the controller to reach the higher temperature on the outside was used as a means to through-heat the part more rapidly. This is believed to have happened because there was not a large enough temperature differential between the inside surface and the outside surface. Because the pads were touching the valve so close to the thermocouple, the temperature did not rise high enough above 500°F to create that differential. The data recorder was then turned on, the power meter was set to record, and the resistance heating power source was set to preheat. Both the data recorder and the power meter record time along with the other measurements. Once both the internal and external measurement thermocouples reached 500°F, the machine

was set to maintain the temperature for one hour and the time on the data recorder and power meter were noted. After one hour, the machine was turned off and the temperature was recorded for another hour after making note of the time on the data recorder. Throughout the test, the amount of time required to set up and tear down was recorded.

Direct Flame

A 100-lb cylinder of propane was used with a Belchfire® fuel gas and compressed air torch. The valve was rotated on a turntable while the flame impinged on the exterior surface of the valve — Fig. 3.

The valve was not insulated at all, which is in accordance with typical industry practices. The data recorder was placed on top of a piece of pipe tacked to the valve so as to not tangle the thermocouple leads. Only the two data recorder thermocouple leads were used for this test.

The data recorder was turned on and the flame and rotation were started. Once both thermocouples reached 500°F, the time was noted and the maintenance time started. Preheat maintenance was determined by monitoring the temperature and cycling the torch on and off manually. This human element can add some degree of inconsistency. After one hour of preheat maintenance, no additional heat was applied and the temperatures were recorded for one hour after making note of the time on the data recorder. Throughout the test, the amount of time required to set up and tear down was recorded.

Experimental Results

Time

Time was evaluated based on time to preheat to 500°F, time difference between inside and outside reaching 500°F, time to set up, and time to tear down.

Preheat Time

When analyzing preheat time, induction produced the best results with both the inside and outside of the valve reaching the minimum 500°F in 0.6 h. The outside of the valve reached the minimum 500°F in only 0.5 h. There was minimal difference in the results from flame and resistance preheating. Achieving 500°F on the outside with the propane required 1.02

h, while the inside required 1.1 h. The outside with the resistance required 0.78 h, while the inside required 1.75 h. Therefore, resistance heating required the greatest amount of time to achieve through-thickness preheating. Overall, the method that brought the inside and outside to the target temperature the fastest was induction.

Setup and Tear-Down Time

The flame method required the least amount of setup and tear-down time, only taking 0.25 h for each. The induction method was next with 0.58 h to set up and 0.6 h to tear down. Resistance required the longest time with 1.5 h to set

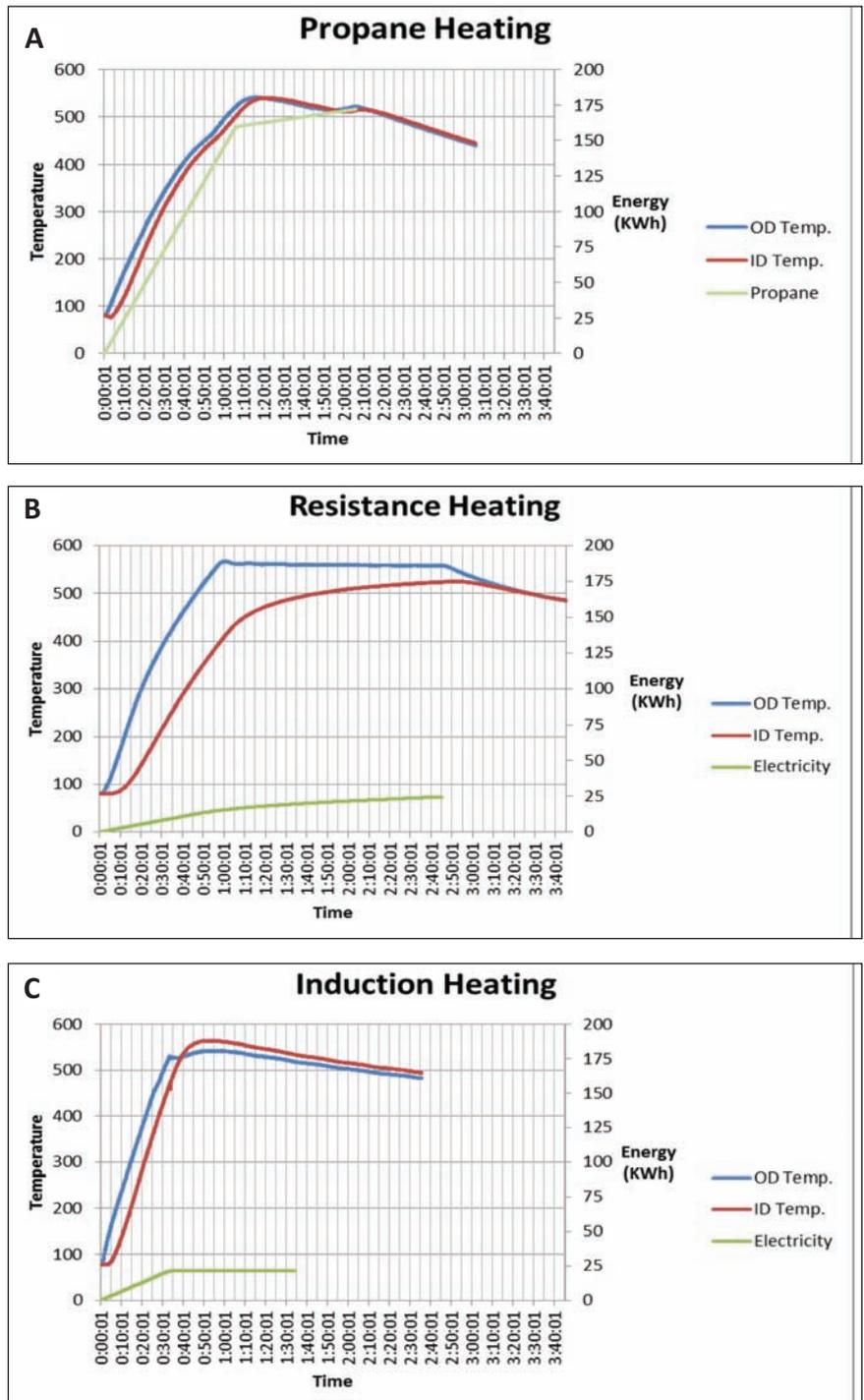


Fig. 4 — Comparison between the temperature rise on the inside and outside vs. the energy used. A — Propane heating; B — resistance heating; C — induction heating.

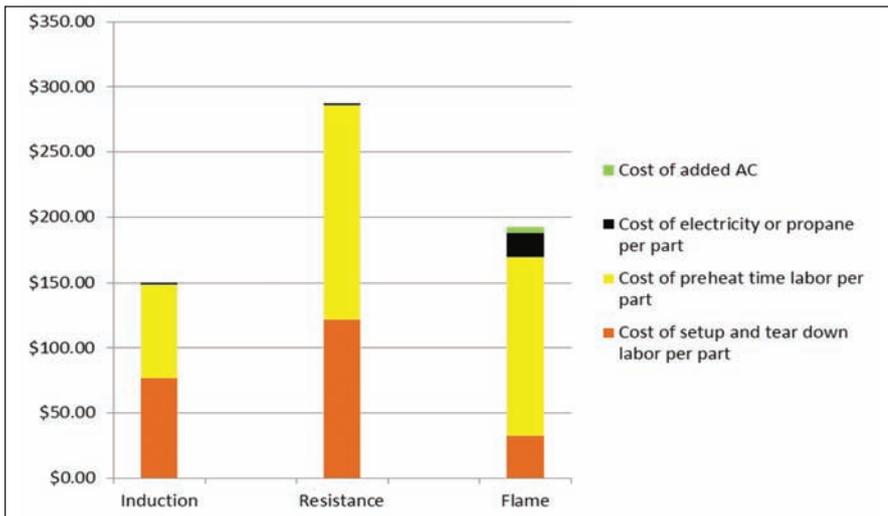


Fig. 5 — Cost per part after the preheat equipment is paid off

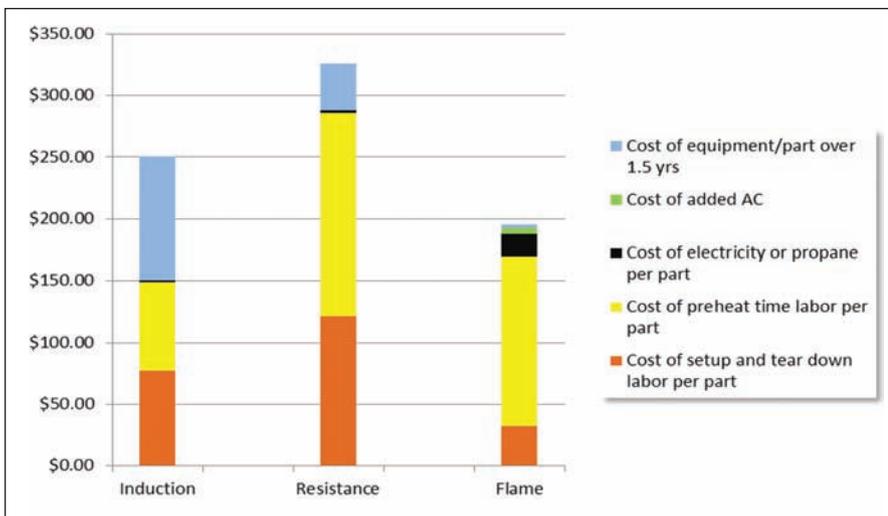


Fig 6. — Cost per part while paying off the preheat equipment (1.5 years)..

up and 0.37 h to tear down. Ease of setup and tear-down was also considered, and direct flame was the easiest. The direct flame method only required the valve to be rotated with a torch pointed at it, while the other methods required more complicated preparation. The only constraint with the propane method is if the part is too heavy for a turntable. The most difficult method was the resistance; with the reality that the operator must wire tie the pads to each other and in the desired position, as well as deal with hot pads once the part is preheated. Induction was significantly easier than resistance to set up, with the self-supporting coils and the additional advantage that the coil does not get hot. The quickest method of the three was propane, with induction a close second, and resistance a lagging third.

Energy Efficiency

Each method's efficiency was analyzed based on energy (generated and consumed) as well as total energy used. For resistance and induction, the kilowatt-hours (kWh) were recorded. For the flame test, the pounds of propane used were recorded for the preheat and preheat maintenance stages. In order to compare all three methods, the pounds of propane were converted to BTU1 and then to kWh2. The amounts of electricity used in the other tests were converted to BTU2 so that all three tests have kWh and BTU as values in relation to the temperature increase.

Flame preheating was the least efficient, using 171 kWh and 585,000 BTU. Flame also had the quickest temperature drop once heat was removed, with a 12°F

difference between the inside and the outside. The quick temperature drop was easily predicted because there was no insulation used for the propane test. The induction method was the most efficient, using 21.5 kWh and 73,000 BTU and had the smallest temperature drop once heat was removed, with only a 4°F difference. The resistance used 24.5 kWh and 84,000 BTU. The outside temperature dropped 34°F more than the inside. The difference can be linked to the requirement that the outside needed to be heated to 550°F in order for the inside to reach 500°F. Once the heat was removed, the outside and inside temperatures were still equalizing, and once the temperatures were the same they both started dropping. One of the most significant differences was the observation that the propane used 585,000 BTU compared to 73,000 BTU for induction. Therefore, 512,000 BTU (87.5%) of energy was wasted. Also, theoretically all 512,000 BTU went into heating the environment, meaning that in production situations, the wasted energy resulted in greater heat exposure to welders and other workers in the area. Induction proved to be the most efficient, using the least energy and having the slowest temperature drop — Fig. 4A–C.

Safety

Each method was analyzed to determine its level of safety based on the amount of handling and potential hazards. Safety was evaluated because it is one of the primary concerns in shop environments. Induction is the safest method out of the three. The part does not need to be on a turntable, which eliminated one part-handling operation. Also, the induction coils remain at room temperature at all times and with the part wrapped in an insulating blanket, the user has a very small chance of getting burned by the 500° F part.

Resistance and propane are hazardous for multiple reasons, but propane is slightly more dangerous. With resistance and propane, the heating elements and torch are extremely hot during and immediately after preheating, and are only cooled by the air. With resistance, the pads are covered with an insulating blanket, but once the part is preheated it is difficult to move the hot pads. With direct flame, the part is not covered at all so there is a large part that will be at the preheated temperature that the operator has no protection from. Also, with direct flame, there is an open flame as well as

Table 1 — Summary of Test Results

Method	Induction	Resistance	Flame
Equipment	Miller Pro Heat 35	PDS Bartech	Belchfire torch
Total propane used, lb	N/A	N/A	27
Total electricity used, kWh	21.6	24.6	N/A
Total energy used, BTU	73,000	84,000	585,000
Avg. temperature drop in 1 h/outside diameter vs. inside diameter temperature differential, °F	36/4	56/34	76/12
Time to preheat inside to 500°F, h	0.60	1.75	1.10
Set up time, h	0.58	1.50	0.25
Tear-down time, h	0.60	0.37	0.25
Total time, h	1.78	3.62	1.60
Total cost*	\$150.34	\$287.57	\$187.69

*Costs based on the following values: labor @ \$65/h; electricity @ \$0.064/kWh; propane @ \$0.652/lb.

hoses filled with combustible gas leading to a cylinder of gas or a manifold system. The torch can be knocked over or inadvertently pointed at something or someone that could be burned. Also, the propane torch heats the room creating a less desirable work environment. Induction is the safest method, having a heating element that does not get hot, heating the valve while it is wrapped in insulating blanket, and requiring no part handling. Furthermore, since the part is heated from the inside, induction heating results in less radiant heat exposure.

Cost

The cost of each method was analyzed based on cost of labor, electricity, propane, and personnel usage. An analysis using \$65/h for labor, \$0.064/kWh for electricity, and \$0.652/lb of propane revealed that resistance preheating costs the most to preheat a valve, costing \$287.57. That breaks down to \$164.67 in labor to preheat the valve, \$121.33 in labor to set up and tear down, and \$1.57 in electricity. Direct flame preheating was the next most expensive, costing \$187.68; \$137.58 in labor to preheat the valve, \$32.50 in labor to set up and tear down, and \$17.60 in propane. Finally, induction preheating was the cheapest, costing \$150.34. That breaks down to \$72.04 in labor to preheat the valve, \$76.92 in labor to set up and tear down,

and \$1.38 in electricity.

If the shop is air conditioned, there will be extra electricity used to dissipate the 512,000 BTU put in the room by the propane, \$4.29 of electricity if the unit is specifically sized for this amount of heat. Also, if preheat labor is not taken into account when the shop preheats offline, preheating one part while at the same time welding another, direct flame becomes the cheapest method, followed by induction.

The induction method proved to be the most efficient. With induction making the best use of the operator's time, using the least electricity, and having a very fast uniform heating pattern.

Cost of the unit is another factor in calculating the cost to preheat each valve. The induction unit costs \$39,000 while the resistance unit costs \$15,000, and the flame torch costs \$1,200; but with the time savings with induction, the cost is offset. Preheating with induction will save the user \$37 per part over direct flame and \$137 per part over resistance, once the equipment has been paid for.

Conclusions and Recommendations

Based on this study, the induction method was the best in most categories (Table 1). Induction heating required the least amount of time to preheat, was the most energy efficient, safest, and most

cost-effective. It used less energy than the resistance and the electricity cost less than the propane used. Induction heated the valve the fastest and was quicker to set up than the resistance. The induction method also was the safest for the user, with the whole valve being insulated and heating coils that do not get hot.

If offline heating is employed, propane is the cheapest, but with an open flame this adds heat to the room that adds extra cost, more safety concerns, and creates a less-desirable work environment. With preheat labor not included, induction was the second cheapest. Resistance was the slowest and most expensive in every scenario, due to setup time and the amount of time it took to preheat.

Perhaps the most important result from this study is the fact that many variables need to be evaluated. While the cost of induction heating equipment is greater than that for either the resistance or direct flame method, the efficiencies offered will offset the added cost. Perhaps more importantly, the fact that the induction method creates a safer environment for the worker will help to optimize both productivity and quality. ♦

References

1. www.flameengineering.com
2. Google® calculator

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