Type N versus Type K Thermocouple Comparison in a Brick Kiln

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ABSTRACT

This paper includes a report on an investigation of improvement in thermometric accuracy, thermal stability and life to be realized with the use of a type N versus type K thermocouple thermometer in a brick manufacturing process. In addition to bare wire elements, recent developments in sheath material for mineral-insulated integrally metal-sheathed cable are investigated.

SUBJECT INDEX: Nicrosil-nisil thermocouple thermometers, Thermocouple drift, Temperature sensor comparisons

INTRODUCTION

Traditionally, temperature measurement in the brick industry has been accomplished by type K, R, and S thermocouples. The K has been chosen based on its operating range of -267 °C to 1260 °C and the economics involved. The platinum series R and S couples are used primarily for control due to increased stability.

The environment of the wood-fired brick kiln is a particularly hostile one. The fire is fueled by wood chips and sawdust fed directly into the kiln. The atmosphere consists primarily of carbon monoxide, sulfur trioxide and water vapor with small amounts of alkali, sodium chloride and potassium chloride vapors. Additionally, to ensure complete combustion of the wood materials an oxidizing environment is maintained.

The reasons for the instability in the type K thermocouples are due to some inherent properties in the chromel/alumel material. One problem that occurs with this thermocouple is an effect called short-range ordering. It occurs in a temperature range of about 425 °C to 550 °C, when nickel and chromium atoms in the chromel leg tend to form an ordered crystalline structure. The ordering produces a different metallurgical structure across the thermocouple wire. If a temperature gradient exists across this area, an erroneous emf is produced. The degree of emf change that occurs with this short-range ordering depends upon the thermocouple's thermal history. This phenomenon can occur to a greater degree if the thermocouple remains in this range to soak for a period of time rather than ramping through this temperature range relatively quickly.

Another shortcoming of type K thermocouples is the hysteresis effect that occurs when a type K thermocouple is cycled up and down in temperature above and below 980 °C. The ordering of the crystalline structure changes with each cycle. After the first pass above 980 °C, the type K temperature indication will be accurate (within ANSI limits of error). With each additional cycle after this one, however, the error will increase. The type K thermocouple also experiences a cumulative drift after a period of time at temperatures above 900 °C and a physical defect called "green rot" which is caused by preferential oxidation of the chromel leg. The type K thermocouple's inherent composition allows for internal oxidation as well as external oxidation. This internal oxidation will eventually cause the thermocouple to decalibrate.

TYPE N THERMOCOUPLES

The type N thermocouple was developed a number of years ago to improve on the performance of the K type. These enhancements included increased thermoelectric stability due to decreased effects of oxidation, nuclear transmutation, structural and electronic phenomenon and magnetic transformations. It should be accepted by now that the type N thermocouple has a much higher thermoelectric stability than the type K for the reasons mentioned (1-6). This is particularly true at elevated temperatures. This experimental work was undertaken to determine if this would hold true in different metal-sheathed cable combinations and junction grounding since a large majority of the installed kiln control instrumentation is for the type K thermocouple. Much work has been done in the past five years regarding the sheath material for mineral-insulated integrally metal-sheathed thermocouple cable. This work has been carried out to more fully apply the N thermocouple to higher temperatures. It is at these temperatures that problems of thermoelectric instability associated primarily with chemical contamination and fatigue failure of thermoelements caused by substantially dissimilar sheath alloys has still not been optimized.

Previous work has shown that AISI 310 stainless steel is not well suited as a sheath material in these temperature ranges. For this reason it was omitted from the testing. Additional work has shown that manganese content in the sheath material plays an important role in thermocouple decalibration by vapor phase diffusion through the magnesium oxide insulation. For this reason, a low manganese Inconel 600 sheath material was chosen.

Several organizations have been involved over the past fifteen years in developing a modified Nicrosil sheath material for improved oxidation resistance, reduced failures due to differential thermal expansion, improved ductility and the elimination of drift problems caused by the vapor diffusion of manganese. Three of these modified Nicrosils are included in the experimentation. Compositions are shown in Table I.

TEST PROCEDURE

The goal of the experiment was to determine the most stable thermocouple configuration for the brick kiln environment. With this in mind, four thermocouples of each type were fabricated to provide several different combinations of data comparison. Table II represents the probe configurations.

The thermocouples were manufactured and an initial calibration performed on each of the probes. This included a check of the insulation resistance at room temperature and calibrations at the following temperatures: 0 °C, 500 °C, 1000 °C.

With these records complete, the probes were installed into the brick kiln. Mounting was horizontal in an upper section of the kiln. Open-ended mullite tubes were built into the three

Table I

Nominal Chemical Compositions of Sheath Alloys

ALLOY	Chemical Composition (weight per cent)							
	Cr	Nb	Mn	Si	Mg	Cu	Fe	Ni
*I600	15.5	-	< 1.0	> 0.5	-	< 0.5	8.0	b
**Nicrobell B	14.5	1.8	-	1.4	0.2	-	-	b
**Nicrobell C	24.0	0.5	-	1.4	0.2	-	-	b
***Nicrosil +	14.2	-	-	1.4	0.2	-	-	b

*Inconel (I600) is a registered trade name for the INCO family of companies
**Nicrobell is a registered trade mark of NICROBELL Pty, Ltd.
***Nicrosil + is a registered trade mark of Pyrotenax Australia Pty.

Table II

Experimental Thermocouples

Type	Grounding	Dia	Sheath	No. Probes
K	U	6.35 mm	Inconel 600	4
K	G	6.35 mm	Inconel 600	4
K	U	6.35 mm	Nicrobell B	4
K	G	6.35 mm	Nicrobell B	4
N	U	6.35 mm	Inconel 600	4
N	G	6.35 mm	Inconel 600	4
N	U	6.35 mm	Nicrobell B	4
N	G	6.35 mm	Nicrobell B	4
K	U	2.95 mm	Nicrosil +	4
K	G	2.95 mm	Nicrosil +	4
K	U	6.0 mm	Nicrobell C	1
N	U	6.0 mm	Nicrobell C	1
K*		3.25 mm	Beaded 8awg	4
N*		3.25 mm	Beaded 8awg	4

*These probes were installed without ceramic protection tubes

foot thick walls. Each probe was manufactured for a 1.12m immersion.

The subject kiln was a continuous push tunnel kiln with constant firing and temperatures ranging from 1000 °C to 1095 °C. Readings were taken in situ approximately every 100 hours.

At approximately 1000 and 2000 hours of continuous exposure, the thermocouples were removed from the kiln and taken back to the calibration laboratory for comparison drift data and physical inspection.

RESULTS

The first noticeable result of the 1000 hour soak was the complete failure of the beaded type K probes. This was to be expected in the sulfurous environment of the kiln. These were included to provide a comparison to the beaded 8 awg type N probes. At the 1000 hour juncture in the experiment, three of the four original beaded N thermocouples were still within ANSI standard limits of error (7.6 °C at 1000 °C). In later experimentation, additional probes were fabricated, calibrated and installed in closed end alumina protection tubes to provide comparison to a more protected environment. After 200 hours of heat treatment, the beaded 8 awg type K probes displayed a decalibration of -34.2 °C. The type N thermocouples under the same conditions exhibited a drift of -2.9 °C.

Table III provides a comparison of the type N metal-sheathed probes as a group to the type K of the same design at 1000 °C. The N thermocouples exhibited a 3.96 °C drift compared to 15.16 °C for the type K after 1000 hours. From a starting total of twenty-four K metal-sheathed thermocouples, seven drifted beyond the ANSI standard limits of error. Six of these displayed drift of greater than 20 °C. A similar comparison of the type N calibration included a starting number of probes at sixteen. After 1000 hours of heat treatment, two of the probes had failed.

Table III

Temperature Drift in °C by Thermocouple Calibration after 1000 and 2000 hours of exposure at 1000 °C

T/C Type	1000 hours	2000 hours
$\bar{K}$	15.16	29.58
N	3.96	8.11

After calibrations at 1000 hours of exposure, the probes were re-installed to soak for a similar period. After a total of 2000 hours of exposure, the type K thermocouples exhibited a drift of 29.58 °C. There was only one type K probe at the 2000 hour mark that was within the ANSI standard limits of error. An average was calculated with nine of the readings, however, because they were still within a range of decalibration (15.1 to 43.6 °C) that would appear to be reasonable in a control room. This is not to say that a 43 degree shift in temperature would not be noticed by brick kiln technicians, but that this magnitude of drift over 2000 hours and at 1000 degrees could be compensated for by a controller without large adjustments and detection.

Similar calculations with the type N probes resulted in an average decalibration of 8.11 °C after 2000 hours of exposure. Six of the sixteen re-installed probes were within ANSI standard limits of error. Additionally, four of the remaining ten probes displayed a drift of less than 20 °C.

This set of comparisons, the type K versus type N, was performed to confirm previous findings. All combinations of sheath and grounding were included to level out the individual effect of any particular configuration.

As noted in the test procedure description, several types of commercially available sheath materials were compared in this hostile environment. Based on previous work done with Inconel 600 sheath (8), a low manganese Inconel composition was specified in ordering the sheath material. This was readily available as a commercial product. The Nicrosil+ sheath was available only in the 2.95 mm diameter and K calibration. The Nicrobell B and Nicrobell C products obtained are both available in the diameter and calibrations specified.

Grouping the probes into similar sheath materials, Table IV illustrates that the Nicrobell B-sheathed probes exhibited a drift at 1000 ^{o}C after 1000 hours of exposure of 6.07 ^{o}C.

Table IV

Temperature Drift in ^{o}C by Sheath Material after 1000 and 2000 hours of exposure at 1000 ^{o}C

	1000 hours	2000 hours
I600	8.90	29.74
Nicrosil +	15.65	- **
Nicrobell B	6.07	7.95
Nicrobell C*	17.35	-

* Initial population included only 1 probe of each calibration, K and N. At time of publication, probes had not reached the 2000 hour exposure level

** All probes had failed by the 2000 hour exposure level

Comparable data on the Inconel 600 and Nicrosil+ probes resulted in respective drifts of 8.90 and 15.65 ^{o}C. The Nicrobell C-sheathed probes gave vastly different results by thermocouple type. Additionally, only one probe of each calibration was included, due to material availability. The type K Nicrobell C sheath demonstrated a drift of -33.6 ^{o}C, while the type N calibration decalibrated by only 1.1 ^{o}C.

These sheath comparisons were made to demonstrate any differences in calibration stability by metal sheath material for this environment. Changes of this type could occur from contamination by chemical elements, particularly manganese, which diffuse through the compacted insulation from dissimilar sheath types. This contamination results in a change in composition of the thermocouple itself and therefore, contributes a major portion of the decallibration. With the knowledge that every one percent of manganese in the sheath material contributes approximately -10 ^{o}C calibration shift for 1000 hours at 1100 ^{o}C (9), a practically attainable low manganese Inconel (less than .24%) was used.

Table V illustrates that the ungrounded type N probe with Nicrobell C sheath exhibited the best drift performance at 1000 hours. Decalibration of only 1.1 ^{o}C had occurred. The results of the Inconel 600 and Nicrobell B-sheathed type N probes were relatively close to this value. These calibrated numbers were -2.68 and -2.98 ^{o}C respectively. At the time of publication, data was not available regarding the performance of the Nicrobell C sheath at the 2000 hour juncture. The results of the Nicrobell B and Inconel type N elements were drifts of -1.9 and 6.5 ^{o}C respectively.

Mechanical stresses between the sheath and thermocouple conductors are not present in this configuration. Additionally, as the conductors are isolated from the sheath, the sheath material itself does not have as large an effect on decalibration except through possible diffusion of sheath components to the thermocouple.

Similar comparison of the ungrounded type K probes with Inconel 600, Nicrosil and Nicrobell B sheath exhibited -13.45, -10.9 and -10.7 ^{o}C drift respectively at 1000 hours. As can be seen, the type K decalibration compared to the type N was considerably more severe. This is further highlighted at the 2000 hour juncture with decalibration values of -26.5 and -15.4 ^{o}C for the Inconel and Nicrobell B sheaths respectively.

Comparing the grounded probe results, the type N Nicrobell B - sheathed probes performed the best with a decalibration of 3.45 ^{o}C at 1000 hours. The type N Inconel 600 - sheathed probes exhibited more considerable drift with 9.60 ^{o}C.

Table V

Temperature Drift Comparison in ^{o}C by Probe Configuration after 1000 hours of exposure at 1000 ^{o}C

	UNGROUNDED		GROUNDED	
	K	N	K	N
I600	-13.45	-2.68	-9.89	9.60
Nicrobell B	-10.7	-2.98	-7.15	3.45
Nicrobell C	-33.6	1.1	NA	NA
Nicrosil +	-10.9	NA	-20.4	NA
Bare K	All Unprotected Probes Failed			
Bare N	2.38			

The type K probe values were -20.4, -9.89 and -7.15 ^{o}C for the sheath materials of Nicrosil +, Inconel 600 and Nicrobell B respectively. These drifts are maintained relatively at 2000 hours of data, as shown in Table VI. The grounding of the probes to the sheath illustrates the effect of the sheath material compatibility to the thermocouple conductors. Differences in thermal expansion between the sheath and the conductors actually results in cold-working of the elements. With this added mechanical change to the thermoelement, decalibration has resulted.

Table VI

Temperature Drift Comparison in ^{o}C by Probe Configuration after 2000 hours of exposure at 1000 ^{o}C

	UNGROUNDED K	UNGROUNDED N	GROUNDED K	GROUNDED N
I600	-26.5	6.5	-64.8	21.15
Nicrobell B	-15.4	-1.9	-11.6	2.9
Nicrosil +	Failed	NA	Failed	NA
Bare K	All Unprotected Probes Failed			
Bare N	-15.9			

CONCLUSIONS

In preparation for this experimentation the author could not find a single source in which, concurrently, the comparisons of grounding, sheath and calibration effects were studied. Additionally, in an effort to provide the best solution to the temperature measurement challenges in the wood-fired brick kiln, beaded 8 awg bare wire thermocouples were also included.

The individual characteristic comparisons showed that in general the ungrounded probes performed better than the grounded probes of the same calibration and sheath material. The primary difference is the reduction of thermal expansion differences and mechanical stresses inherently present in a grounded configuration. by taking a closer look, at 2000 hours, this enhancement was optimized by choosing a sheath material that closely matched in composition, that of the thermocouple legs. With this, the effect of migration was minimized.

The beaded thermocouples did not perform as well as the metal-sheathed. All of the type K unprotected probes failed before 1000 hours of heat treatment. The hardiness demonstrated by the type N unprotected bare wire corresponded to the life demonstrated by the Nicrobell-sheathed thermocouples. Since both Nicrobell B and Nicrobell C are derivations on the N thermocouple legs, this would appear to confirm this composition as a basis for protection in this particularly hostile environment.

When placed in closed-end alumina protection tubes, the life was improved. However, the decalibration of the type K versus the type N was still more severe. The beaded type K element placed in alumina protection tubes had drifted -49.4 ^{o}C at 1000 hours of exposure. For this same time period, the beaded N element decalibrated by 1.9 ^{o}C.

Generally, for the heat treatment condition of a continuous 1000 ^{o}C, the type N thermocouple had a substantially better thermal stability than the type K. The selection of sheath material was important in minimizing the decalibration, as well as providing protection for survival in this environment. Although the probes had not reached the 2000 hour soak point, the Nicrobell C sheath composition in combination with the type N thermocouple provided the greatest thermal stability.

RECOMMENDATIONS

The gains in improved thermal stability realized by combining the N thermocouple with a sheath of similar composition has been demonstrated. For the environment of the wood-fired brick kiln, the Nicrobell C metal sheathed type N thermocouple provided the best thermal stability. Using this result in combination with the longevity increase expected, JMS will proceed in further testing of the Nicrobell C sheath material in this and other harsh environments. Additional data should be available by the fall of 1992. Inquires may be directed to the author.

To find a sheath and thermocouple in combination that will not only survive a hostile environment, but also optimize the thermal stability may point to a future of reduced inventories. A larger range of temperature solutions may be provided with a single sheath/thermocouple combination.

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