PROCEEDINGS OF THERMAL IMAGING FOR REFRACTORY INSPECTION AND PLANT MAINTENANCE

June 24, 1975

Pittsburgh, Pennsylvania

AGA

Edited by Jan K. Eklund, AGA Corporation

FOREWORD TO STEEL PROCEEDINGS

The first seminar dealing specifically with the use of thermography in refractory lining and plant inspection was held in Pittsburgh, Pennsylvania on June 24, 1975.

This seminar was conducted in order to convey the most recent development in application technology and hardware connected with thermal imaging in the various areas of iron and steel making. Representatives of the major steel companies and AGA discussed topics including the detection of eroded or lost refractory in blast furnaces, hot stoves, gas mains, BOF:s, AOD:s, as well as documentation of wear patterns.

The proceedings of the seminar represent the most comprehensive report on the current use of real time infrared imaging in iron and steel making and its benefits to the industry, specifically the prevention of unscheduled shut downs, the help of increasing the life span for various steel making vessels, energy conservation, and optimizing equipment to its most efficient uses.

Based on the interest displayed by the large number of participants at the seminar, we believe that these proceedints will be useful to the reader in evaluating the current thermographic inspecting practices with a view towards implementing what serves the best interest of his company.

AGA Corporation

Jan K. Eklund,
Editor

ABSTRACTS

UTILIZATION OF THERMAL INSPECTION FOR STEEL PLANT MAINTENANCE

John Pagath
Advanced Research, Research and Technology
Armco Steel Corporation
Middletown, Ohio

The Thermovision has been employed to make periodic thermal inspections in many areas of the steel mill complex. Primarily, the instrument has been used to pinpoint areas where there has been a loss of refractory material in various stoves, stacks, duct-work, and vessels which are used to contain hot materials or gasses. In addition, electrical substations and power lines are inspected at regular intervals.

This report includes reference thermograms of the various areas of interest and compares these to some which were made after extended period of operation or the necessary repairs had been made. Examined in detail will be a blast furnace complex, the open hearth furnace duct work, a direct iron ore reduction plant, lime stone kilns and hot metal cars used to transport pig iron. Several examples are also given to indicate the wide variety of useful applications of the instrument within other mill areas.

THERMAL IMAGING TECHNIQUES APPLIED TO SOLVING STEEL PLANT PROBLEMS

Samuel B. Prellwitz
Section Supervisor
Electrical Systems Division, Research Laboratory
United States Steel Corporation
Monroeville, Pennsylvania

Infrared imaging techniques provide television-like images directly from infrared radiation emitted by the source object. The image is usually photographed for a permanent record. Images can be made of objects at temperatures ranging from normal outdoor temperatures up through steelmaking temperatures. A great deal of information about the condition of process equipment and treatment of steel in process can be learned through the use of thermal imaging because the thermal image paints a complete pattern of surface temperature. The recent availability of rugged, precise equipment to make thermal images almost instantaneously has made this technique a practical industrial tool for maintenance and problem analysis. Use of this equipment in U.S. Steel is discussed along with examples of practical problem analysis.

A SIMPLIFIED APPROACH TO QUANTITATIVE ESTIMATION OF REFRACTORY LINING THICKNESS ON CERTAIN VESSELS

Rutger Johansson
Market Project Manager, Steel
AGA Infrared Systems AB
Lidingö, Sweden

Thermography has gained widespread and increasing acceptance as a suitable method for plant condition monitoring in the steel industry. This method permits the hottest region of an installation to be located immediately and the temperature of that region to be obtained within minutes. In case of a reasonably simple structure, a knowledge of the outer surface temperature will allow wall thickness to be calculated. This paper indicates the vast possibilites of the method and presents a discussion of significant parameters to be considered in the analyses of thermal patterns and the use of programmable calculators for a simplified approach to these problems.

THERMOVISION MONITORING OF STEEL REFINING VESSELS

Arthur M. Brandenburg
Technical Specialist, Manufacturing and Applications Engineering
Colt Industries—Crucible Steel
Pittsburgh, Pennsylvania

Variations in temperature over the surfaces of Argon-Oxygen Decarburization shell and the Basic Oxygen vessel were established as isotherm patterns through analysis of data procured using the AGA Thermovision Model 750 with Color Monitor. Color photographs taken from the Thermovision presentation over a series of heats, indicate little or no change in the general shape of thermal patterns, although there were some changes in temperature.

THE USE OF THERMOGRAPHY ON SINTER PLANTS

P.J. Watson
General Steels Division
British Steel Corporation
United Kingdom

In the work of improving the overall efficiency of a sinter plant, the search for an ideal thermal pattern across the strand was included. This paper presents a discussion of the results obtained as well as interpretations made and remedial actions taken.

UTILIZATION OF THERMAL INSPECTION FOR STEEL PLANT MAINTENANCE

J.G. Pagath, Jr.
Advanced Research,
Research and Technology
Armco Steel Corporation
Middletown, Ohio

While almost all forms of Non-Destructive Testing have been used in Armco's preventive maintenance programs, the use of the infrared camera for thermal inspections has been uniquely successful in many applications. In this paper, we will present some examples of how the technique has been used to pinpoint potential problem areas in the steel mill.

The Thermovision has been used not only for routine inspections in some areas, but has also been used to detect potential problems on a non-scheduled basis. In our inspections programs, we, as members of the Research Staff, cooperate fully with plant maintenance personnel conducting inspections at their request and sometimes at our suggestion. Primarily, our efforts thus far have been directed toward the inspection of refractory lined furnaces, duct work, and vessels used to transport hot metal in several plants of Armco. Periodic inspection of the electrical power substations at most of the company facilities are also made.

FIGURE 1

The blast furnace complex, shown in Figure 1, was the first area where thermal inspections were made. The primary areas of concern are the uptakes and downcomer, stoves, hot blast main, and dust collector and these will be discussed in detail. This large, shaft type furnace is used to reduce the oxides of iron present in the ore to metallic iron and to flux off the impurities. The product is pig iron in liquid form for further processing. Here, where down-time is costly in terms of hot metal loss and where repair work is very time consuming, the technique has proved very beneficial in locating possible problem areas and indicating the extent of the necessary rework or repairs.

Initially, a thermal inspection was made of the blast furnace "downcomer." This duct, which is 16 ft. in diameter, carries the 600° F dust laden gases from the top of the furnace to a dust collector where it is cleaned and the remaining "off" gas is used for auxiliary fuel. Prior to a major rebuild, the Thermovision was used to inspect this section of the furnace in an attempt to determine the extent of rework which may be required. Figure 2 is a montage of the uptakes, downcomer, and dust collector top showing several hot spots in the junction of the uptakes and downcomer and in the elbow area above the dust catcher. In addition, there is evidence of separations between the welded wear plates in the unlined section of the downcover.

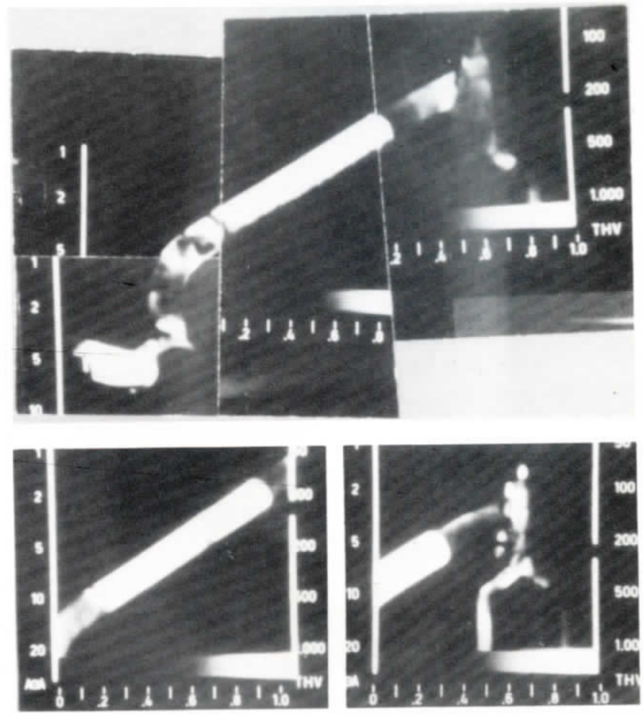


FIGURE 2

Based partly on the above inspection results, the entire downcomer and elbow were replaced and the upper section repaired. The thermograms shown at the bottom of Figure 2 were made after this replacement and as can be seen, the hot spots are no longer present.

Heat rings in another blast furnace dust collector are steps in the internal brickwork. The hot spots are the internal support arms. No problem areas here. This is shown in Figures 3a and 3b.

In a third blast furnace, personnel found bricks in the water discharge line. By identifying the type of brick, they knew the general location of its origin.

We were called to this blast furnace in an attempt to locate the exact section or sections. Three areas were suspected; the converging, throat and diverging sections of the scrubber system. The Thermograms revealed only portions of the converging and throat sections had lost some brick. See Figures 4a-d and 5a-d.

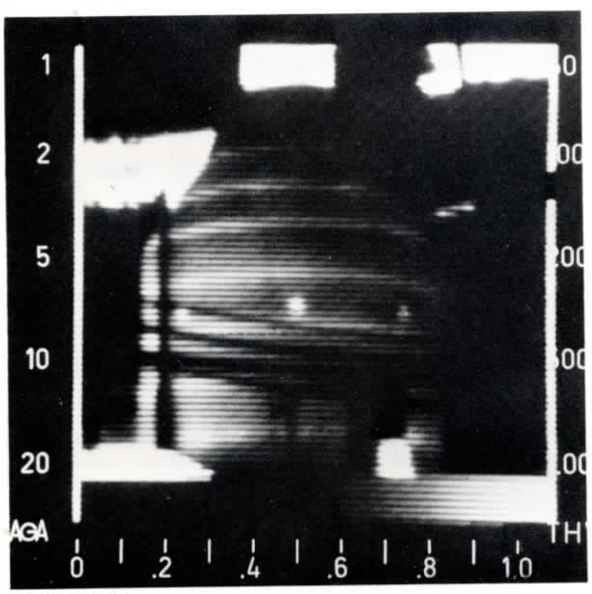


FIGURE 3a

FIGURE 3b

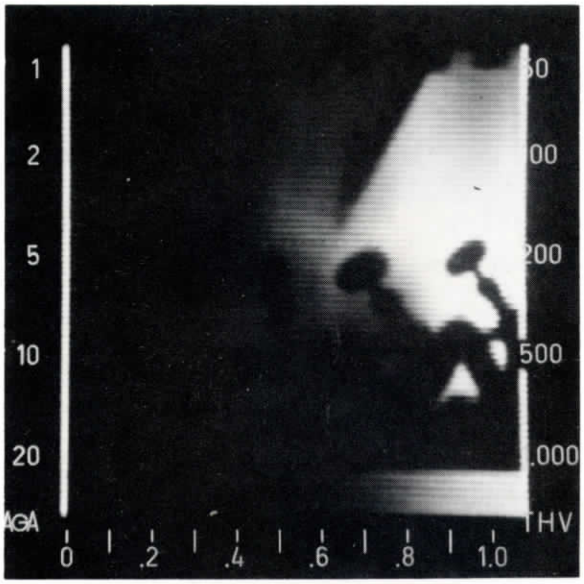


FIGURE 5a

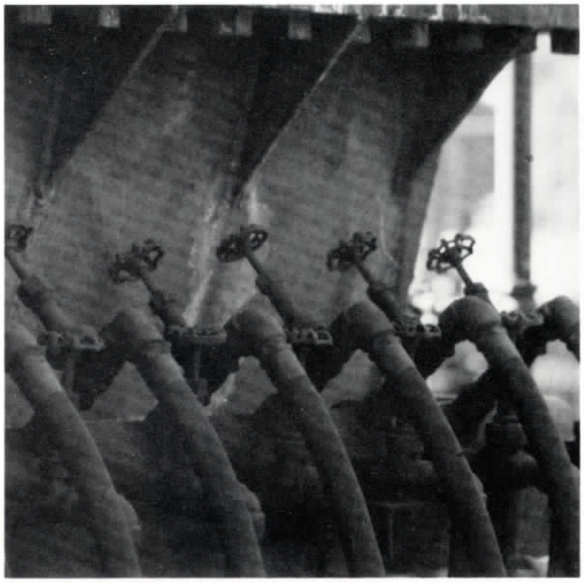


FIGURE 5b

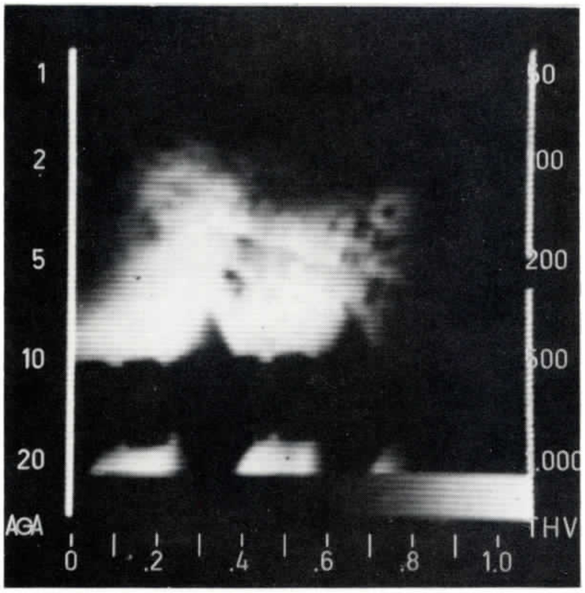


FIGURE 5c

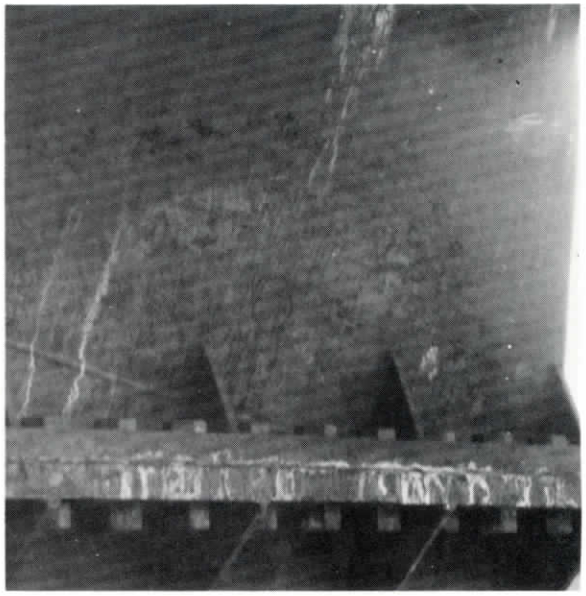


FIGURE 5d

The blast furnace stoves are refractory lined vessels which are divided into two chambers. One chamber is an open combustion space and the other is filled with nested checker brick. The fuel is burned in the combustion section and the hot gases give up their heat to the checkerwork during a heat up cycle. When the stove "goes on blast" the hot gases flow in the opposite direction and on to the furnace. Each stove serves to heat the total blast requirement for the Blast Furnace for about 1 hour.

Two hot spots were discovered in No. 1 Stove, shown in Figures 6a and 6b. Figures 6c and 6d are close-ups of No. 1 Stove. These spots indicate either loose or cracked brick but at the time of inspection no great operating hazard.

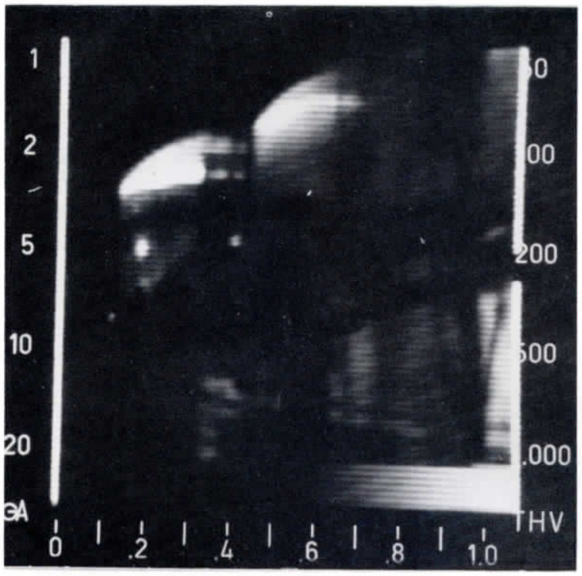


FIGURE 6a

FIGURE 6b

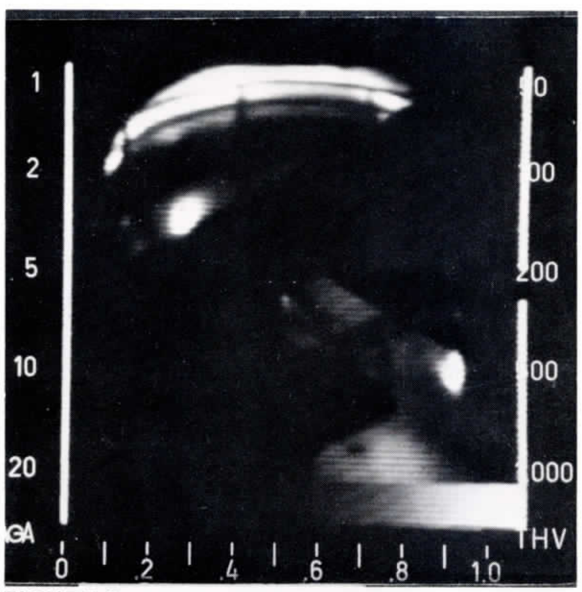


FIGURE 6c

FIGURE 6d

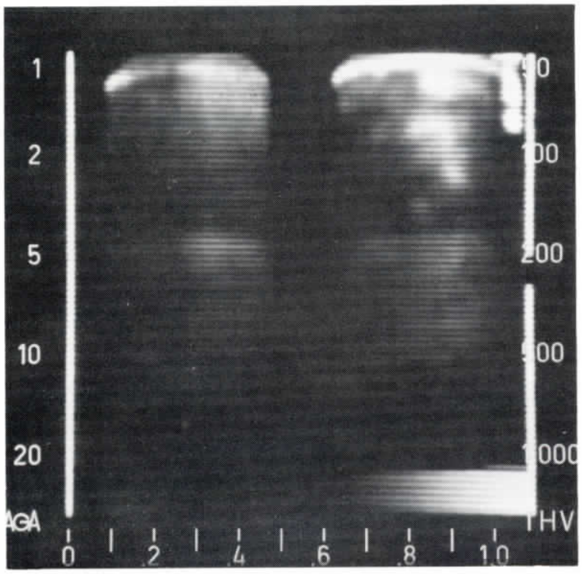


FIGURE 7a

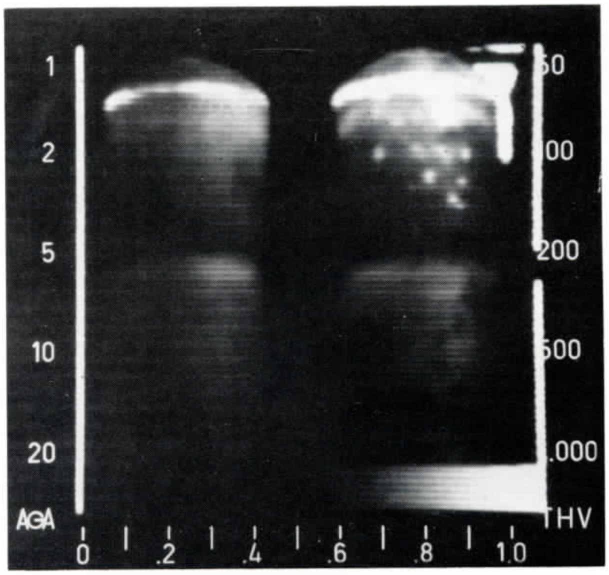


FIGURE 7b

In the thermogram on Figure 7b, No. 1 Stove (on the right) is on blast. When a stove is on blast, the greatest movements of the hottest gases takes place. All inspections of stoves are completed during the blast cycle. No. 2 Stove on left in right thermogram has uniform thermal patterns but is not on blast. In the left thermogram, Figure 7a, No. 2 Stove (on the left) is on blast and still has a uniform heat pattern. No. 1 Stove on the right is starting to "soak out" causing the spots to merge into a single hot area. Ore pile seen in Figure 7c is not visible in thermograms.

At the top of Figure 8 is a photograph of the hot blast main which interconnects the stoves with the furnace. During an evening shift, a glowing hot spot appeared on the upper surface. The following day, the lower left thermogram was made showing the hot spot that was seen at the top went completely around the duct. On visual inspection during the next shutdown, it was found that a complete row of bricks had fallen from around the circumference. These were replaced and the present condition is shown at the lower right. Here, the thermal map provided some indication as to the amount of rework necessary.

FIGURE 7c

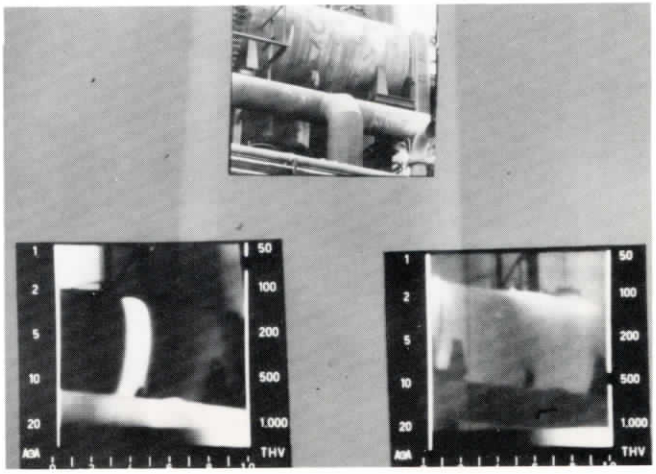


FIGURE 8

Figures 9a and 9b shows the emergency cold blast main. This line supplies a cold blast into the hot blast main in an emergency situation. There should be no gas movement, nor elevated gas temperature in this line during normal operations.

A recently opened direct reduction facility at Armco provides yet another example of the use of thermal inspections for maintenance. See Figure 10. By direct reduction, we mean the chemical conversion of iron oxide to iron *without* going through the liquid state. In the direct reduction furnace, iron ore or iron oxide pellets which are 67% Fe are charged into the top and hot reducing gas ($CO+H_2$) is blown up through this column. At the bottom, the reduced ore, now about 92% Fe, is removed and is further refined to steel in an electric furnace. The areas of interest here are similar to those in the blast furnace.

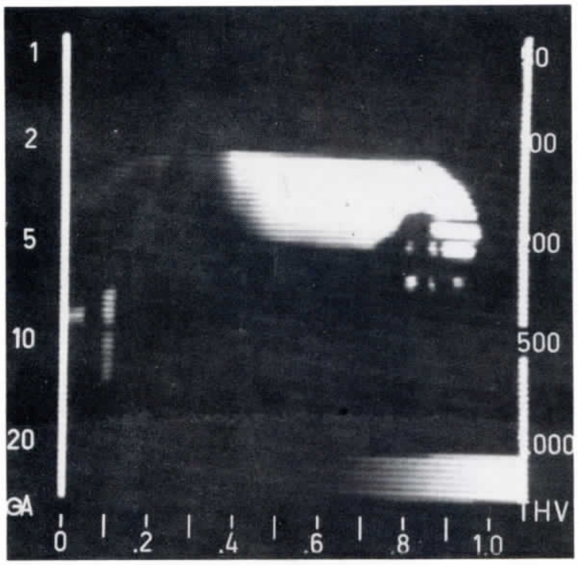


FIGURE 9a

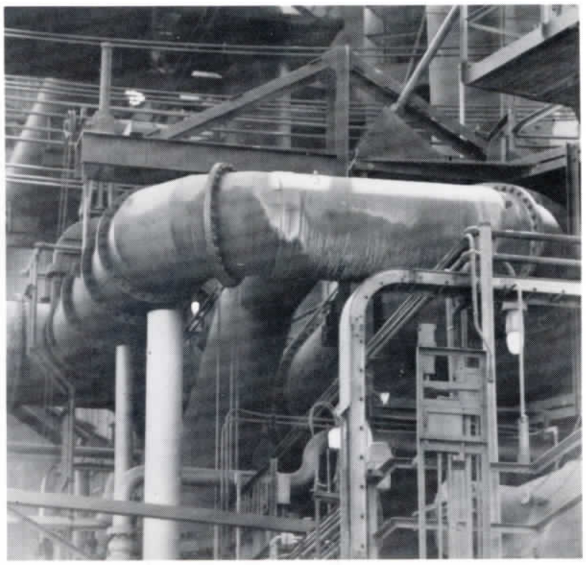


FIGURE 9b

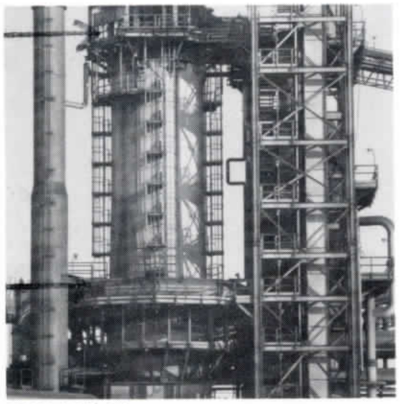


FIGURE 10

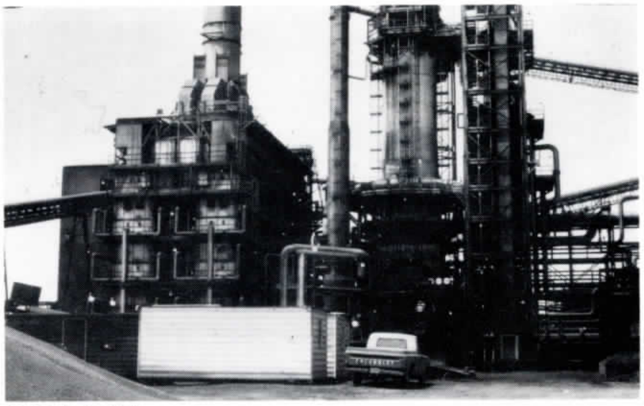


FIGURE 11

The next thermograms, Figures 12a-d, were taken from here, through a steel grating floor to directly below to here. See Figure 11.

$CO+H_2$ gases enter the bustle pipe and through 12 tuyeres into the DR shaft. The area where the tuyeres join the bustle pipe was suspected of containing loose or thin refractory brick. As seen in Figures 12a-d there is an uneven thermal pattern. The thermograms are mirror images of the real pictures.

Although there are varied heat patterns, nothing in these pictures, Figures 13a-h, is considered unusual. Heat rings in this picture are internal support rings for the brickwork. See Figure 13e.

A preheated mixture of methane and steam is introduced at the top of the reformer unit. These gases go through high alloy tubes which are heated by top gas-fired burners. The exit gases are $CO+H_2$ and go to the bustle pipe at the direct reduction furnace. See Figure 14a-14d.

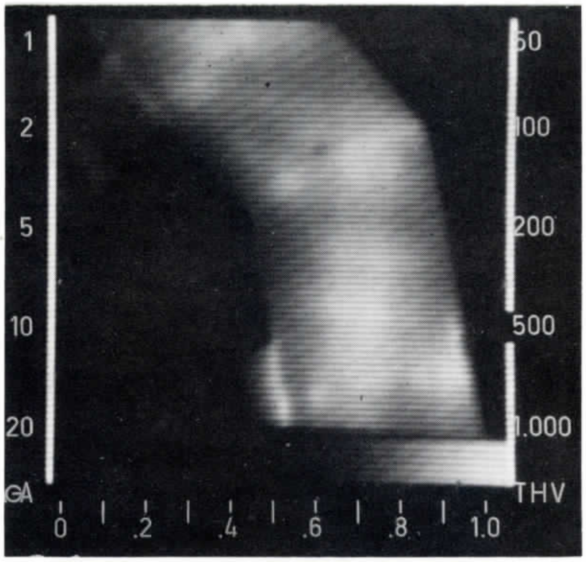


FIGURE 12a

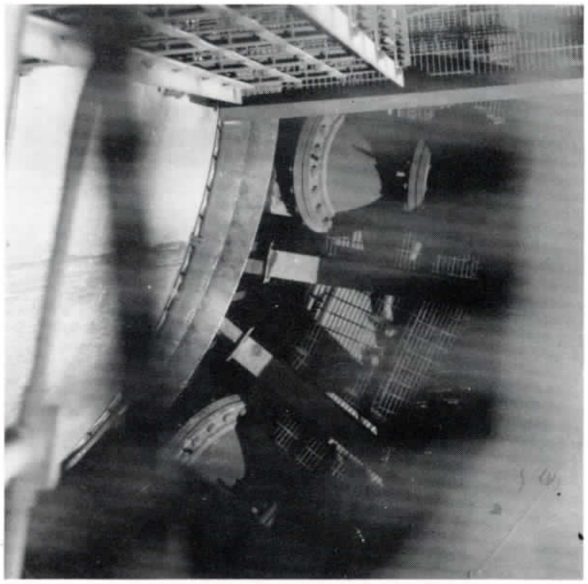


FIGURE 12b

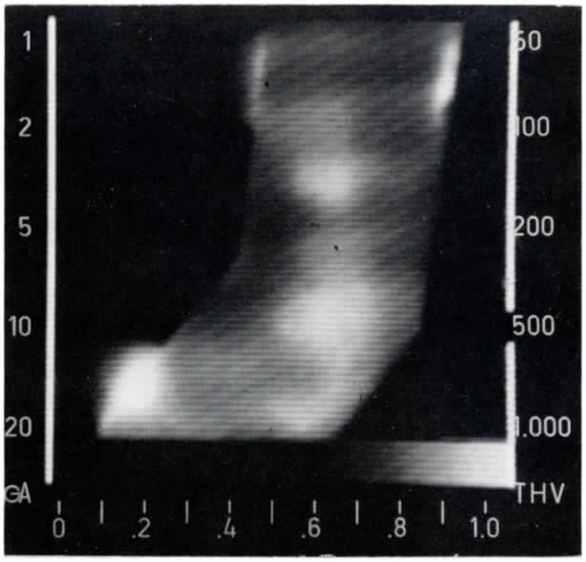


FIGURE 12c

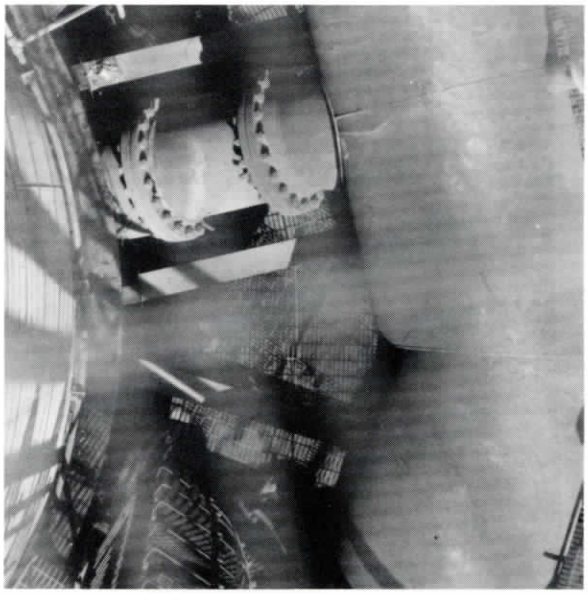


FIGURE 12d

FIGURE 13a

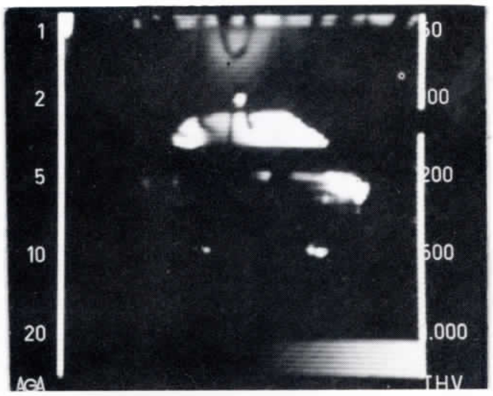


FIGURE 13b

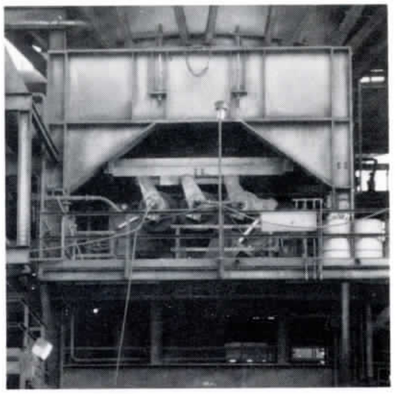


FIGURE 13c

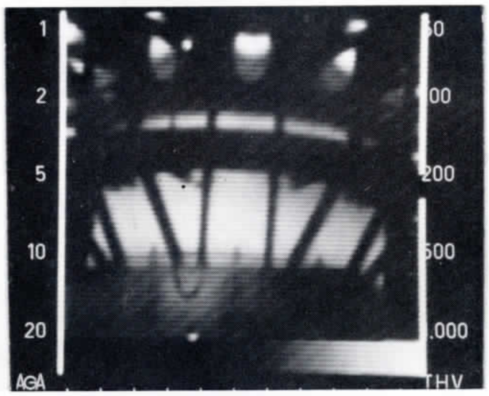


FIGURE 13d

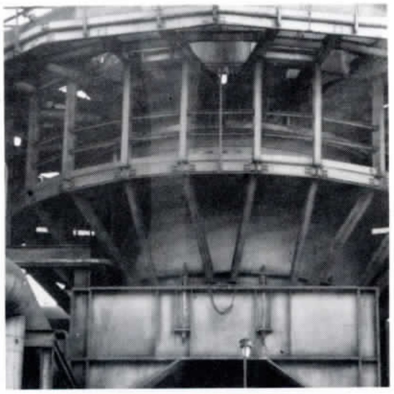


FIGURE 13e

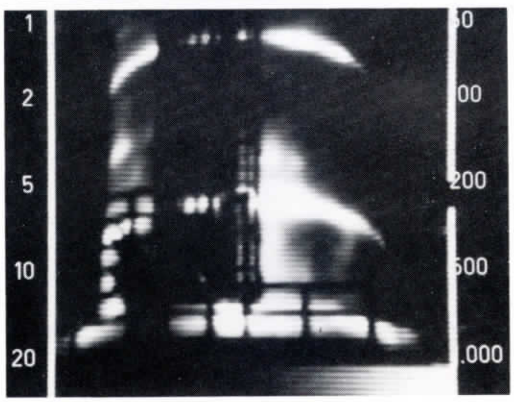


FIGURE 13f

FIGURE 13g

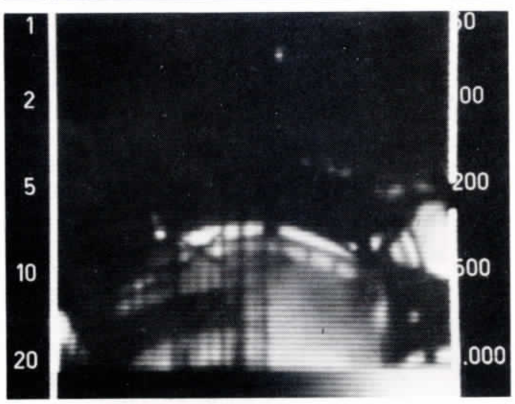
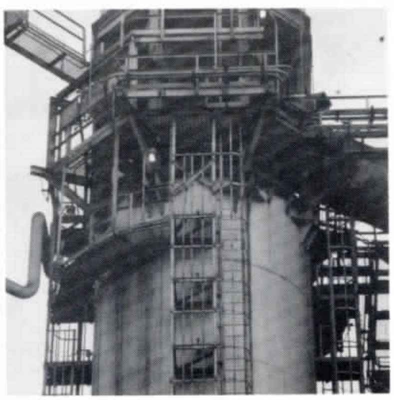


FIGURE 13h



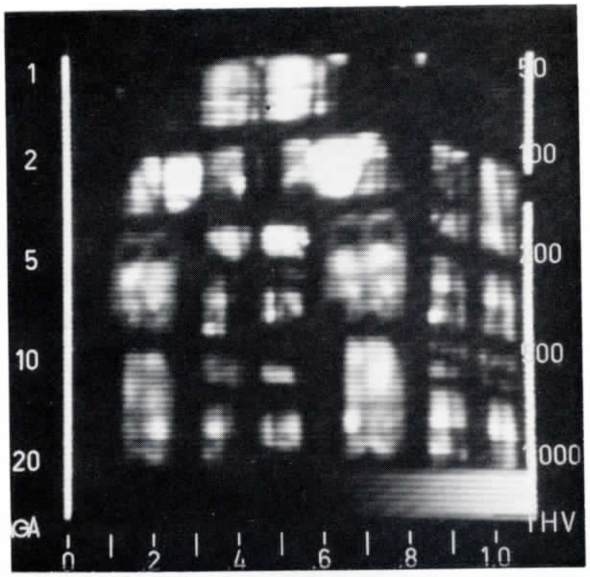


FIGURE 14a

FIGURE 14b

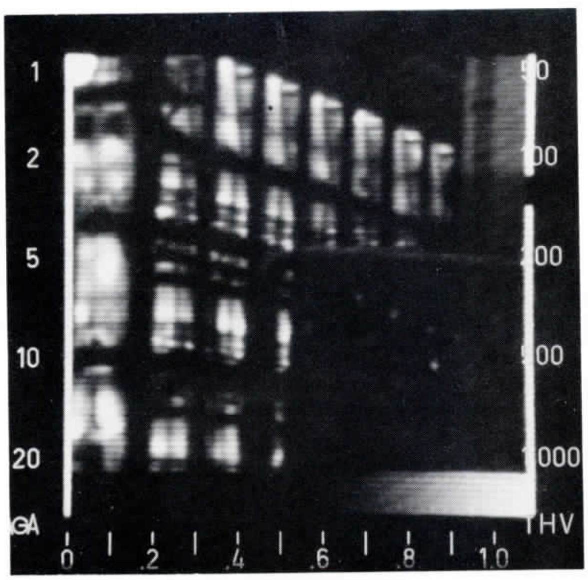


FIGURE 14c

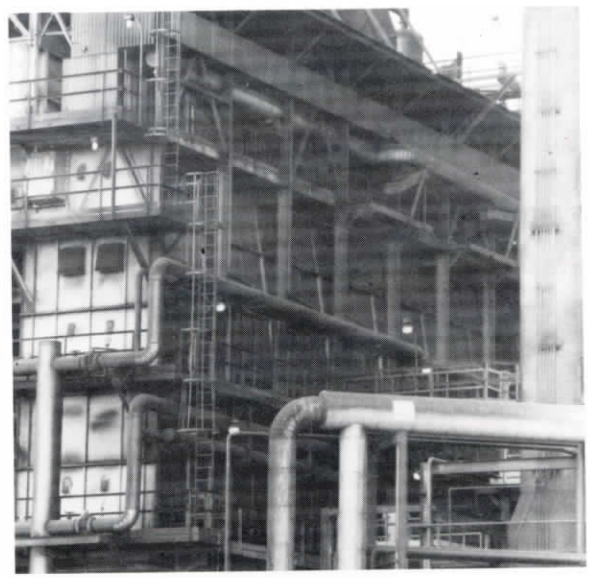


FIGURE 14d

Another inspection program, shown in Figure 15, concerns Pugh-type hot metal cars used to transport pig iron from the blast furnace to other processing areas. These cars are refractory lined vessels which can carry up to 300 tons of molten metal. Here, the Thermovision is used to locate hot spots which could lead to dangerous breakouts through the shell of the car. Based on our experience to date, the typical skin temperature of a full car is approximately 380° F. During one inspection, the temperature of a hot spot in the collar area of a car exceeded 650°F and soon after, a breakout occurred. Based on this experience, all hot spots in excess of 600° F are reported and the car, when cooled, is inspected visually and corrective action taken.

FIGURE 15

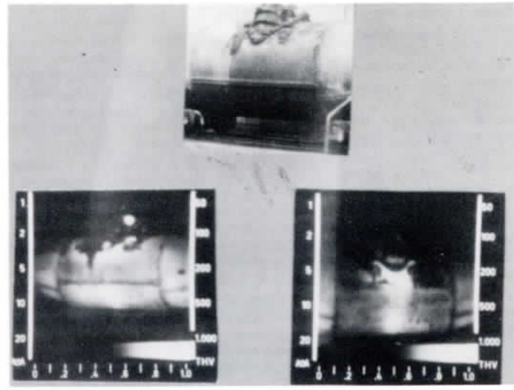


FIGURE 16

Figure 16 shows a hot metal car with a localized hot spot in the collar area. The temperature in this spot was 670° F. When the car was inspected visually, there was evidence that the hot metal had penetrated the mortar between the bricks and solidified. Based on these findings, the car was only filled to one-half of its capacity until repairs could be made.

The cars shown in Figure 16 are typical of most of those in service. When hot spots are detected, they generally occur in the collar area or in the bottom of the ladle where hot metal strikes the bricks

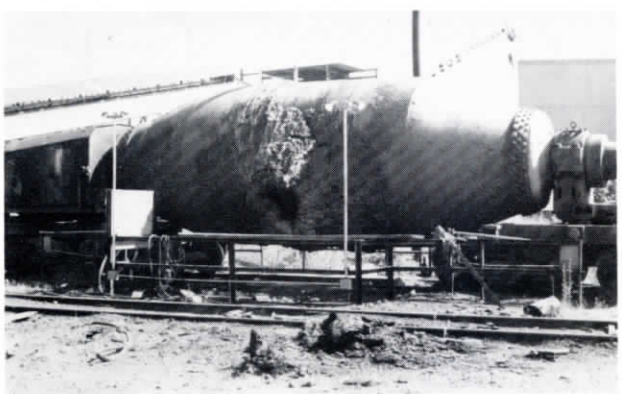


FIGURE 17

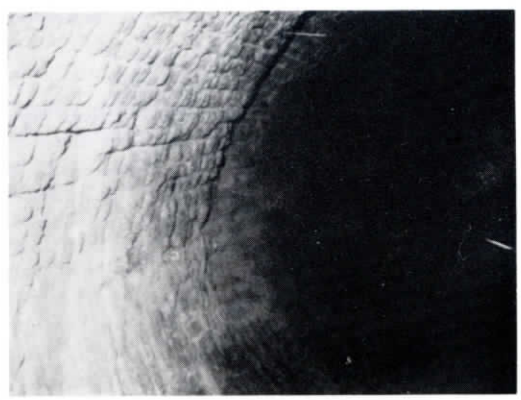


FIGURE 18

directly during casting. Figure 18 was taken inside one of the cars. With the car rotated, the collar area is at the lower right making the bottom at upper left. The cobblestone appearance results from wear in the mortar joints. The groove is caused by hot metal striking the bricks during casting. Some hot areas have also shown at the slag line where there tends to be an erosion due to splashing. Hopefully, the data obtained from these inspections can be used to determine the amount of brick remaining and can be used to predict when relining is necessary.

Figure 17 is a view of a hot metal car in position for repair work. Figure 18 was taken inside this car while in this position. Note cobblestone effect in brickwork.

The smoke abatement duct work for open hearth furnaces is another area which has been inspected. The IR camera allows for a complete survey of all accessible areas of the duct work system in a short time. The ducts (12-15 ft. diameter) carry the hot, dust laden off-gas from the furnace through the wet precipitators and out to the atmosphere.

Figure 19 is a sketch of the duct work in the system along with thermograms of some selected areas. The dotted lines on the sketch outline the areas covered by each frame. In the thermograms at the upper right, bottom and lower left, an isotherm was used to map out the hottest areas. In general, except for the clean out ports, the hot spots were less than 25° above the nominal duct temperature and not considered serious. The thermograms are retained for reference and when the inspection is repeated, any changes in size or temperature will be noted.

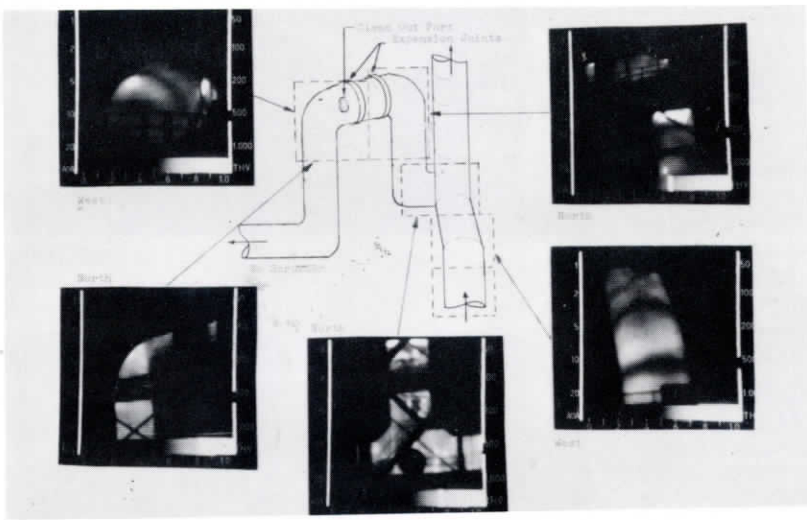


FIGURE 19

Most of the items which have been discussed were concerned with areas where thermal inspections are done as part of a routine maintenance program. In addition to this, a couple of interesting special inspections were requested. One concerned a blockage in a 26" gas main which carries blast furnace off-gas to the coke ovens where it is used for fuel. The coke oven operators had noted that over a period of time, the fuel air ratio was constantly increasing to maintain the ovens at the proper temperature. A differential pressure measurement revealed that there was a restriction somewhere in the transition section shown in Figures 20a-e. Closeup of lower elbow is shown in Figure 20b. With a thermal inspection, the obstruction was found to be at the bottom elbow where apparently the dust and dirt associated with blast furnace gas had accumulated. The thermograms, Figures 20c-d-e, were taken over a six month period as various methods were tried to dissolve the obstruction by injecting steam, chemicals, etc. just above the elbow. As can be seen in the Figure 20e thermogram, the only remaining solid matter present is in the very bottom of the elbow.

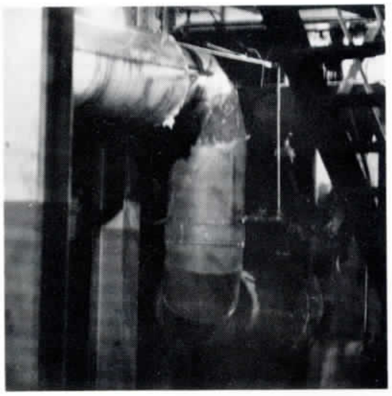


FIGURE 20a

FIGURE 20b

FIGURE 20c

FIGURE 20d

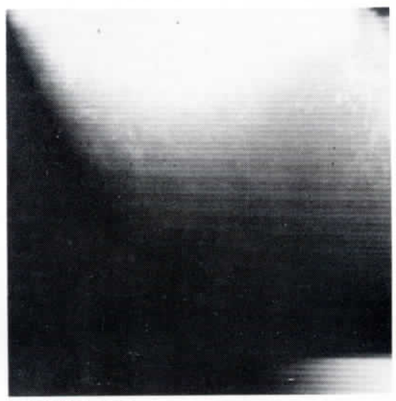


FIGURE 20e

Figure 21 is a view of a kiln at one of our limestone mines. This rotating kiln is 300 ft. long and 10 ft. in diameter. Limestone enters at right into the kiln and moves down and to the left of the picture. Figure 22 is a thermogram showing the firing zone at the left of the kiln. Varied heat patterns are due to thin brick.

FIGURE 21

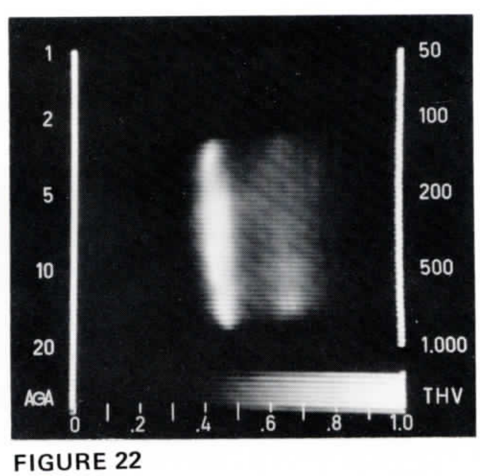


FIGURE 22

Figures 23a and 23b are gas cooling tubes. Gas enters at bottom left at approximately 1300° F and exits at bottom right at 550° F. There are five cooling tubes per kiln.

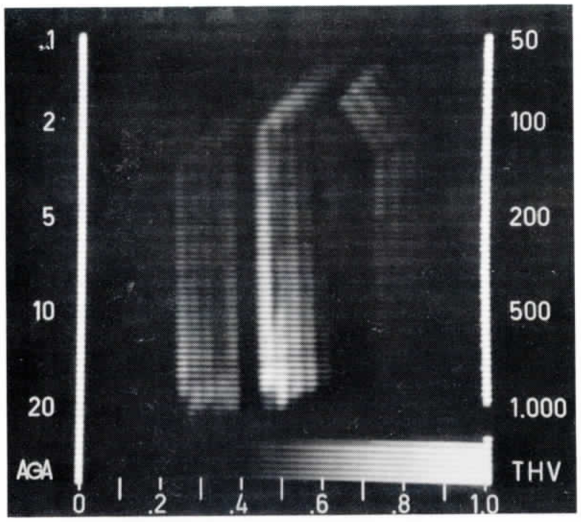


FIGURE 23a

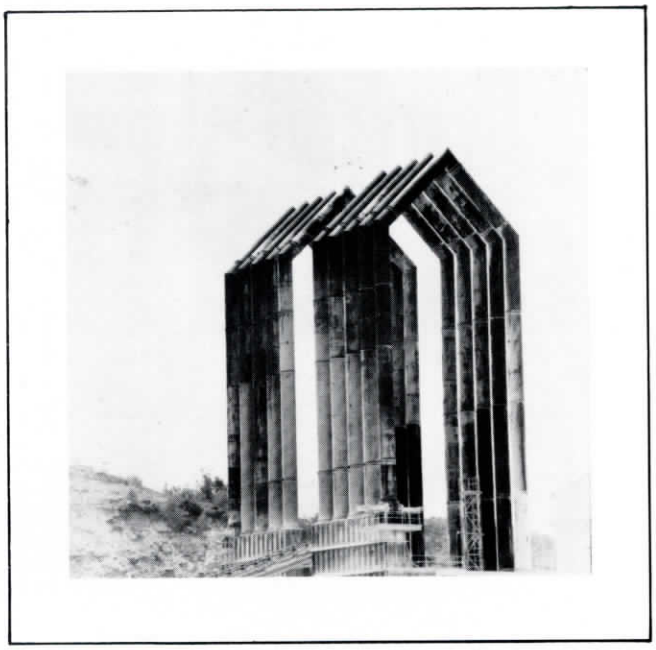


FIGURE 23b

Figure 24 is a close up of the kiln. Heat ring is present because of thin bricks. Two types of brick are used in this area and one type wears more rapidly than the other. Eventually this ring will extend to the right as the wear increases. The dark patch 6'x8' is a piece of aluminum foil between brick and kiln wall. This foil was put in by maintenance foreman as an experiment. The temperature is 25° F cooler on kiln surface at this patch.

FIGURE 24

Another area of concern is gear boxes. There is not much information or data available at this time. Shown in the thermograms, Figures 25a-d, are gear boxes located on a large coupling threading machine. The temperature range is from 110-145° F. There have been bearing problems in these machines and an attempt is being made to see if we can isolate the problem through thermal techniques.

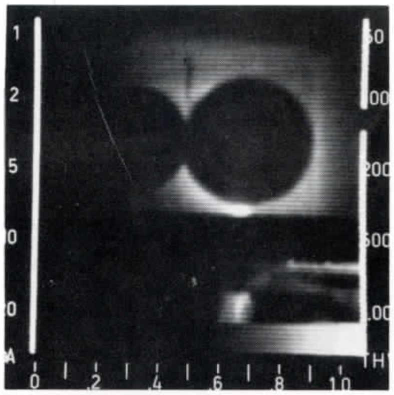


FIGURE 25a

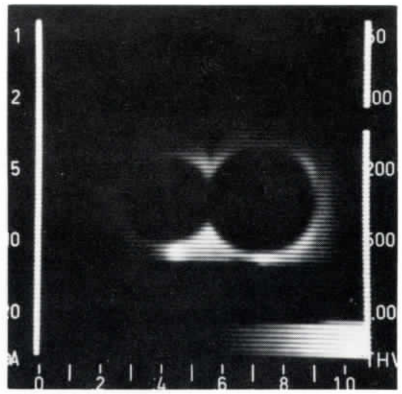


FIGURE 25b

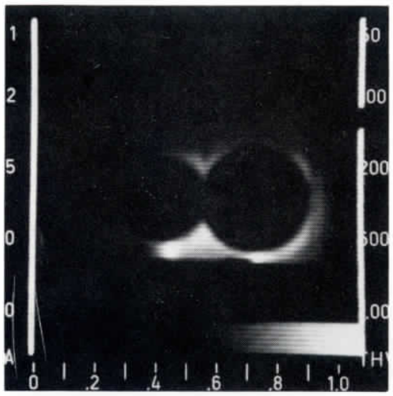


FIGURE 25c

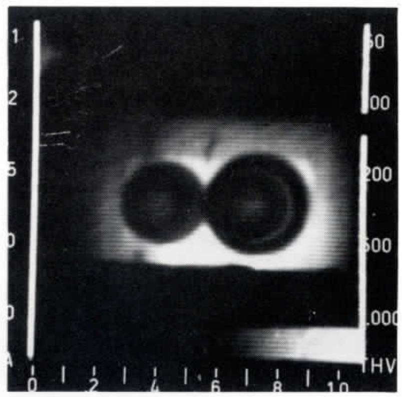


FIGURE 25d

We also do power substation inspection at most of our plants. Inspections are being performed twice a year.

Figure 26 is a picture of a 6.9 kV, 1000 A switch feeding an electric furnace shop.

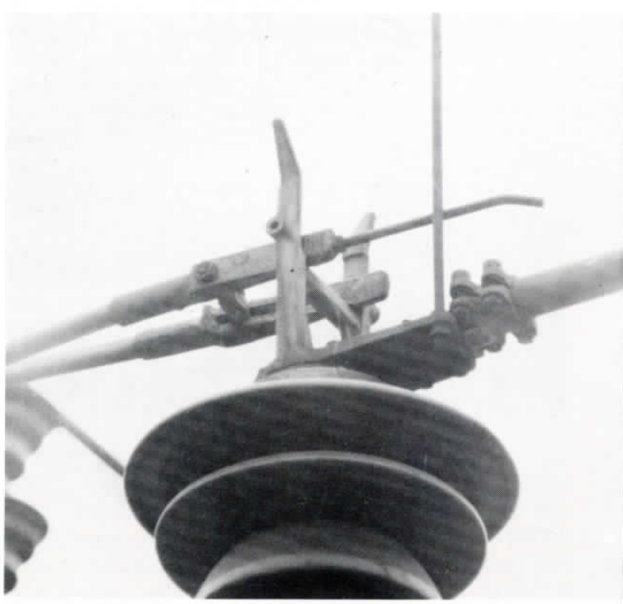


FIGURE 26

The breaker jaw, shown in Figure 27, is typical of those that are defective. Note the wear.

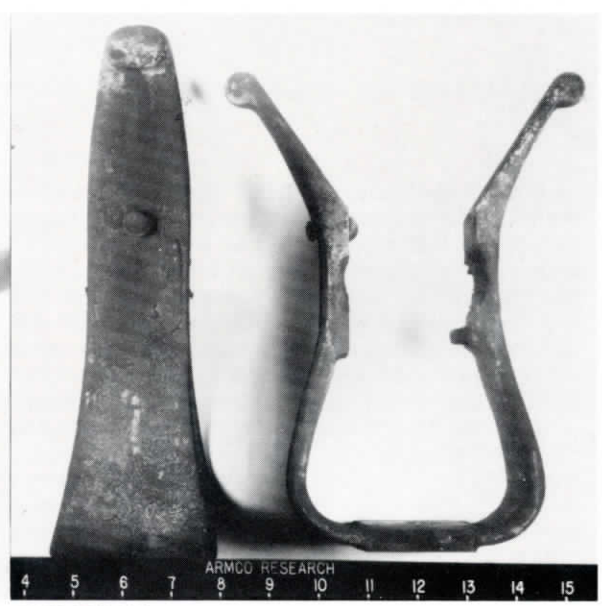


FIGURE 27

Figure 28 is a close up of one side of the breaker jaw. There is intimate contact at one point only. Figure 28b is a thermogram taken during October 1973 inspection of this same switch.

FIGURE 28a

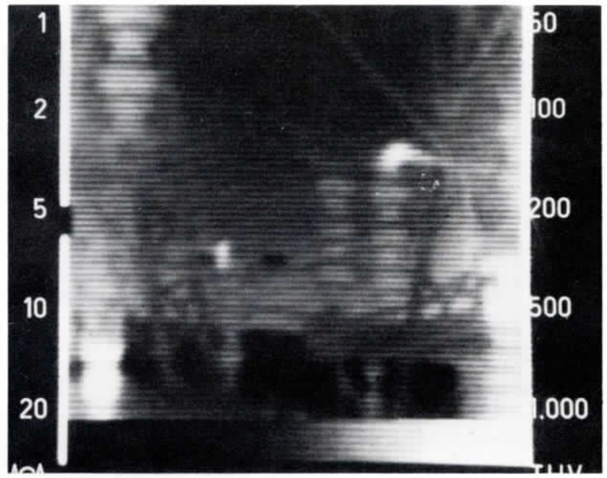


FIGURE 28b

At present, the majority of our Thermovision inspections are done from this van shown in Figure 29. It is a Dodge Maxi-Van which is air-conditioned and has, mounted in the rear, a 5000 W generator. The display unit of the Thermovision rests on a shelf above the passenger section and the infrared camera extends above the hatch on top of the vehicle.

We have found this system to be very satisfactory for our work in power substations, blast furnaces, direct reduction furnace, and even inside electric furnace shops.

FIGURE 29

In this presentation, we have attempted to show some of the ongoing programs involving thermal inspection techniques used at Armco. However, what we have shown is only a part of many potential uses of the system. In general, we feel that the Thermovision has become an invaluable tool not only in terms of the downtime it has saved in some areas, but also in providing information concerning the operation of certain processes. Much more work is anticipated in several areas with, hopefully, the same success.

FIGURE 30

THERMAL IMAGING TECHNIQUES APPLIED TO SOLVING STEEL PLANT PROBLEMS*

Samuel B. Prellwitz
Section Supervisor
Electrical Systems Division,
Research Laboratory
United States Steel Corporation
Monroeville, Pennsylvania

In view of rising costs and urgent need to maintain productivity of plant equipment, operating and maintenance people in plants are ever on the lookout for methods and equipment that are more effective in avoiding unscheduled shutdowns, and in helping to get the most service from equipment consistent with safety and the avoidance of breakdown.

A discipline that is becoming more and more recognized as being useful by operating and maintenance people is that of thermal imaging.

INTRODUCTION

Thermal imaging has its source, as does much of our technology today, in the early 1800's. In March, 1840 experiments were reported by Sir John F.W. Herschel where infrared radiation was imaged on pieces of paper that had been blackened on one side and wet with alcohol. Sir John had been experimenting with the "calorific rays" that had been found by his father, Sir Frederick William Herschel, to exist beyond the red end of the visible spectrum. Sir Frederick had probed the area with thermometers; Sir John imaged the calorific portion using his slips of alcohol-wet paper. The heat energy dispersed by the prism on the blotting paper made dry spots corresponding to certain maxima, and demonstrated that "calorific rays" could be dispersed like their near relative, light, or "optical energy." It was a laboratory demonstration to make a point about the spectrum; Herschel gave the name "thermograph" to the images formed. And as is the case with many laboratory curiosities, the first practical expression came via the military people. In all but the hottest tropical zones, human beings are at a higher temperature than their surroundings at night. Military scientists felt that if their eyes could only "see" the invisible thermal radiation, people would stand out like glowing candles in the dark of the night by virtue of their thermal radiation. An attempt to make an evaporagraphic image using a technique related to that of Herschel was made in 1929 by M. Czerny; a volatile liquid was evaporated selectively from a thin membrane by elements of an infrared image focussed thereon. It took the scientific impetus spurred by World War II and the possibility of seeking targets by their radiated heat to develop the sensitive and high-speed infrared detectors that have become commonplace today in many areas of technology.

Figure 1 shows a portion of the electromagnetic spectrum that contains both visible light and infrared energy—it is shown referenced to the general electromagnetic spectrum from

30 Hz (wavelength = 1×10^9 cm (6214 Miles))

to gamma rays

(wavelength = 1×10^{-10} cm (0.01 Å)).

The light we see is limited to wavelengths from 0.4 to 0.7×10^{-4} cm, expressed as micrometers (μm); the infrared extends from 0.8 μm through 1000 μm. For purposes of classification, the infrared region is separated into 3 bands: near infrared (0.8 to 1.2 μm), mid-infrared (1.2 to 40 μm) and far infrared (40 to 1000 μm). Thermal imaging equipment uses a mid-infrared bandwidth generally between 2 and 12 μm, depending on the equipment, and can generally deal with objects whose temperatures are in range below freezing to ranges at steel making temperatures.

*Presented at the AISE St. Louis, March 1975.

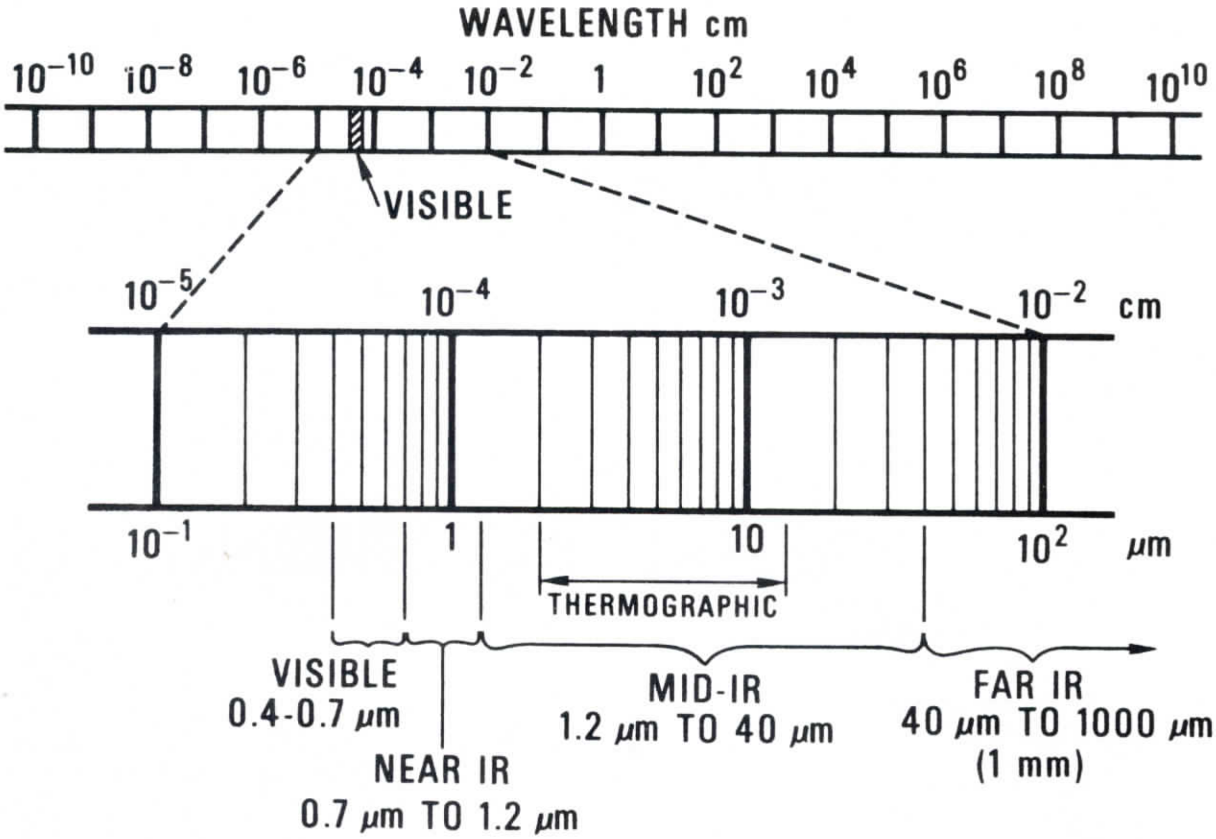


FIGURE 1 The Electromagnetic Spectrum from 10^{-10} cm to 10^{10} cm wavelength, with detail of visible and infrared (IR) wavelengths.

The picture in Figure 2 shows a blast furnace. It was originally taken in color, in that relatively narrow part of the electromagnetic spectrum by which human beings see. A great deal of information is available from the color image: the color of the furnace, the size and shapes of its parts, and its general condition. Figure 3 is a picture of a blast furnace using invisible infrared, or thermal, radiation. The shape of the furnace is still discernible, but a different set of information appears. We now see it in terms of thermal radiation proportional to temperature. The hot offtakes of the furnace become visible as white bars at the top of the furnace. We have overcome the darkness beyond the red end of the spectrum.

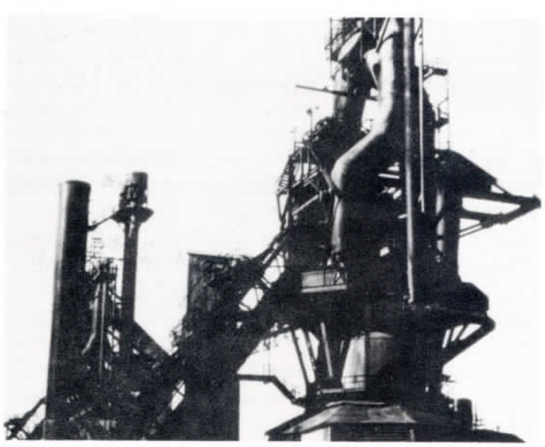


FIGURE 2 Photograph of blast furnace.

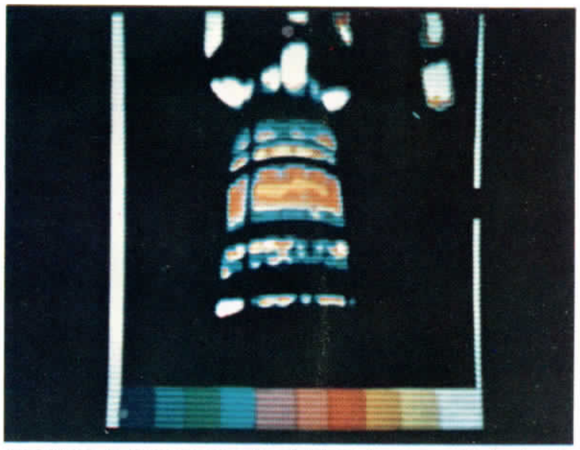


FIGURE 3 Thermograph of blast furnace. Note hotter offtakes at top; dark bands around furnace are catwalks.

The infrared picture was made by a complex instrument system called a thermal-imaging system. This system is a high-speed scanning radiometer that has a television-type readout. (A pyrometer is a special case of a radiometer; its readout scale is calibrated for temperature rather than for radiant energy and provision is made to adjust for emittance.) A highly sensitive infrared detector mechanically scans the field of view focussed on it by a lens designed to transmit and focus infrared energy. The optical system of one commercial thermal imaging system is shown in Figure 4. As the detector scans across the field of view, the electron beam in a special TV picture tube scans in synchronism across its image area, creating a picture whose brighter areas correspond to higher infrared energy. A photograph, together with a black-and-white infrared image (thermograph) of a person is shown in Figure 5. Hair and clothing are normally dark, because they are cooler than body surface. Glasses, transparent in the regular photograph, are black in the thermal image, because optical glass is opaque to the infrared wavelengths used, and the lenses are cool. Figure 6 shows the same image in a color thermograph. The colors are obviously not true; they are arbitrary, and serve only to delineate isotherms, or areas of nearly equal temperature range. The blocks along the bottom of the image split the overall radiant energy range into 10 equal segments. Temperatures corresponding to this range are taken from calibration curves, using a known image temperature together with known range settings, and known or assumed emittance. Most of the images shown are in color; we have found this isotherm display most useful.

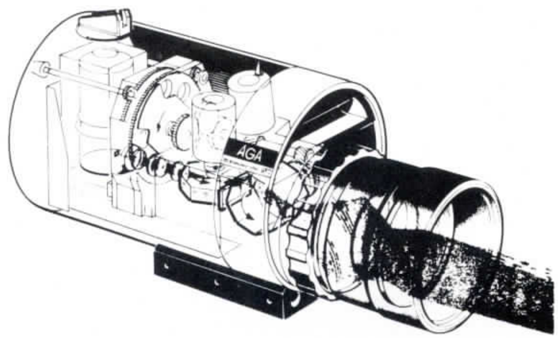


FIGURE 4 Phantom view of thermal imaging camera. The dark band represents path of energy in the system. The first rotating prism generates vertical scan, the second prism generates horizontal scan. The detector is at the bottom of the liquid nitrogen container at the rear of the camera. Aperture disks and chopper are in front of the detector. (Courtesy of AGA Infrared Systems, AB.)

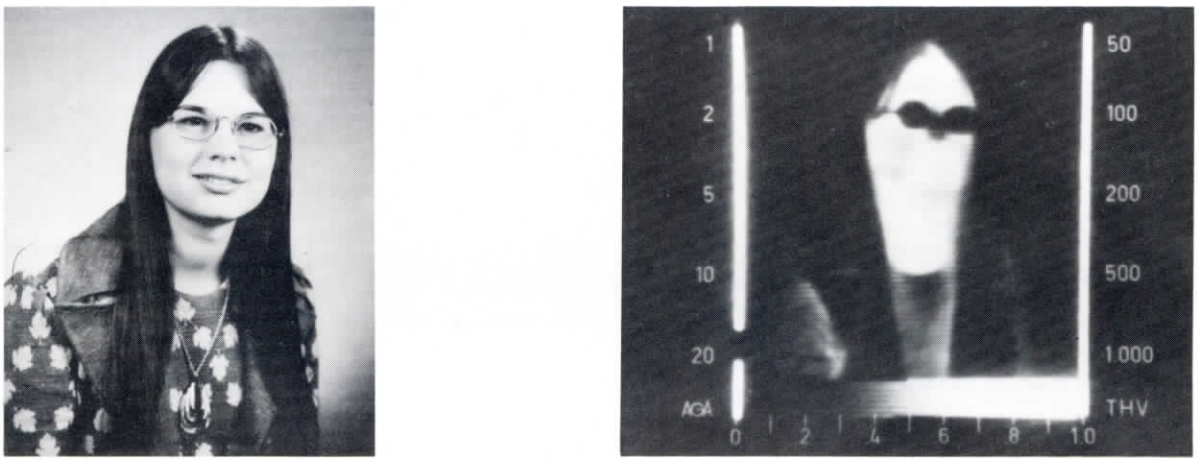


FIGURE 5 Photograph and thermograph compared. Skin area radiates the most energy and appears lightest. Hair radiates little energy because it is cool and appears dark. Lapels on dress are darker than dress because they are cooler due to added layers of cloth. Glasses appear dark because optical glass doesn't transmit infrared energy at the wavelenths used.

FIGURE 6 Thermograph of Figure 5, made on color monitor designed to display isotherms, or areas where radiation is of like intensity. The colors are arbitrary and chosen to separate total range of energy into 10 discrete steps. Blues and greens indicate lower range, reds and yellows the higher range. The isotherm presentation helps in assigning temperature to various parts of an image.

Temperature measurements to within about 5 percent can be made with thermal imaging systems; the process is time consuming, and accurate results depend on accurate knowledge of the emittance of the surface being measured. The thermal imaging systems react to radiant energy, as indicated above, and temperature is related to radiant energy by a fourth-power relationship expressed by the Stefan-Bolzmann law; this relationship is altered in thermal imaging systems, however, by the spectral response of the radiation detector and spectral transmittance of the optics. So a set of specific calibration curves must be used to relate radiation differences to temperature differences. Temperature measurement is best done by the use of a known temperature in the field of view, with ranges about this "known" being calculated by means of the curves and the value of the emittance of the surface. The system in use at U.S. Steel will handle temperatures from −30C (−22F) to 2000C (3632F), with minimum detectable step of 0.2C at 30C. It will not handle the entire range at one setting, however; aperature stops and filters must be brought into play that cover overlapping smaller ranges within the extremes mentioned.

There are two industrial thermal imaging system makers today; comparison of systems that are available from these makers is made in Table I. General illustrations of these systems appear in Figures 7, 8, and 9. All this equipment is generally bulky and heavy, has complex electrical and optical systems, and all require the use of liquid nitrogen to cool the infrared detectors. The camera head typically contains a small thermos-type reservoir that must be replenished frequently during use.

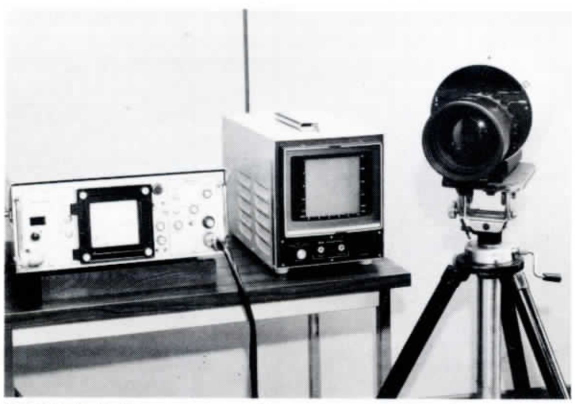


FIGURE 7 The camera, the camera control and video display unit, and the color monitor of the AGA Infrared Systems AB, Thermovision®, Model 680.

FIGURE 8 The Model 750 Thermovision® system by AGA Infrared Systems, AB. It is similar to the bigger Model 680, but has been engineered for portability. (Courtesy of AGA Infrared Systems, AB.)

FIGURE 9 The Spectrotherm Model 800 thermal imaging system. The video display is integral with the camera housing. (Courtesy of the Spectrotherm Company.)

TABLE I

Comparison of Thermal Imaging Equipment

Maker	Spectrotherm	AGA	AGA
Model	800	680	750
Image Time	2 seconds	1/16 seconds	1/25 seconds
Resolution	1.3 milliradians 30° × 30° field of view	1.0 milliradians 8° × 8° field of view 2.5 milliradians 25° × 25° field of view 3.5 milliradians 45° × 45° field of view	3.4 milliradians 20° × 20° field of view 1.2 milliradians 7° × 7° field of view
Display	Storage Oscilloscope	Real time video, black & white and color	Real time video, black & white
Spectral Range	7 to 14 μm	2.0 - 5.6 μm	2.0 - 5.6 μm
Power Supply	120 VAC	120 VAC	120 VAC or battery pack
Detector	HgCdTe - LN_2 Cooled	InSb - LN_2 Cooled	InSb - LN_2 Cooled
Recording	Polaroid Film, 70 mm roll film	Various photographic	Polaroid Film
Temperature Range	−20 C to 420 C (high end can be increased by filters)	−30 C to 850 C, (to 2000 C, with filters)	−20 to 900 C (to 2000 C, with filters)
Minimum detectable temperature difference	0.2 C	0.2 C at 30 C	0.2 C at 30 C

A great deal of information useful to steel plant operators lies in the normally invisible infrared portion of the spectrum. The ability to see directly the patterns of distribution of infrared radiation enables steel plant operators to control processes better and to maintain equipment more effectively. Thermal imaging has been used to show surface temperature distribution on steel in process; on furnaces, ovens and ladles as an indicator of refractory condition and bonding; on electrical equipment to indicate overloads, maldistribution of load, or incipient junction failure; and on process ducts, piping, or storage tanks to show buildup of deposits or to indicate plugging. A thermal image of a group of wires, pipes, or junction points shows the hot ones (or the cold ones); a thermal image pinpoints the hot components on a circuit board, a relay panel, or on commutator or slip-ring brush rigging. And thermal images are made from a distance; because no contact is required, temperatures of electrical components can be measured while their systems are under load. A single thermal image of a surface effectively presents the kind of information that would be given by 30,000 thermocouples embedded in the surface and all read simultaneously. A few details of some of the more interesting work with thermal imaging in U.S. Steel are given below.

Imaging the patterns of temperature distribution on steel in process has been of considerable use to steel plant operators. For example, the thermograph of Figure 10 shows the temperature distri-

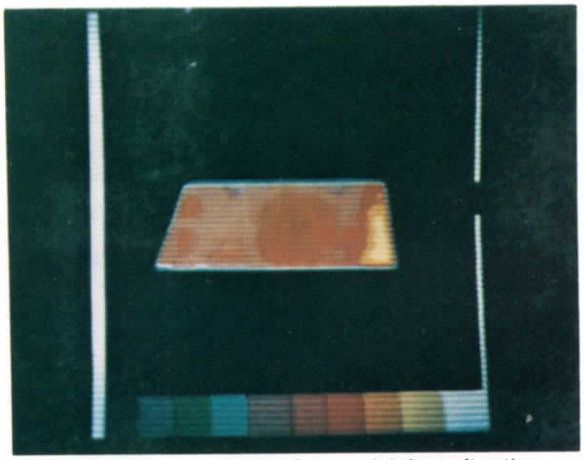


FIGURE 10 Thermograph of plate slab just after the first mill stand, showing temperature gradients.

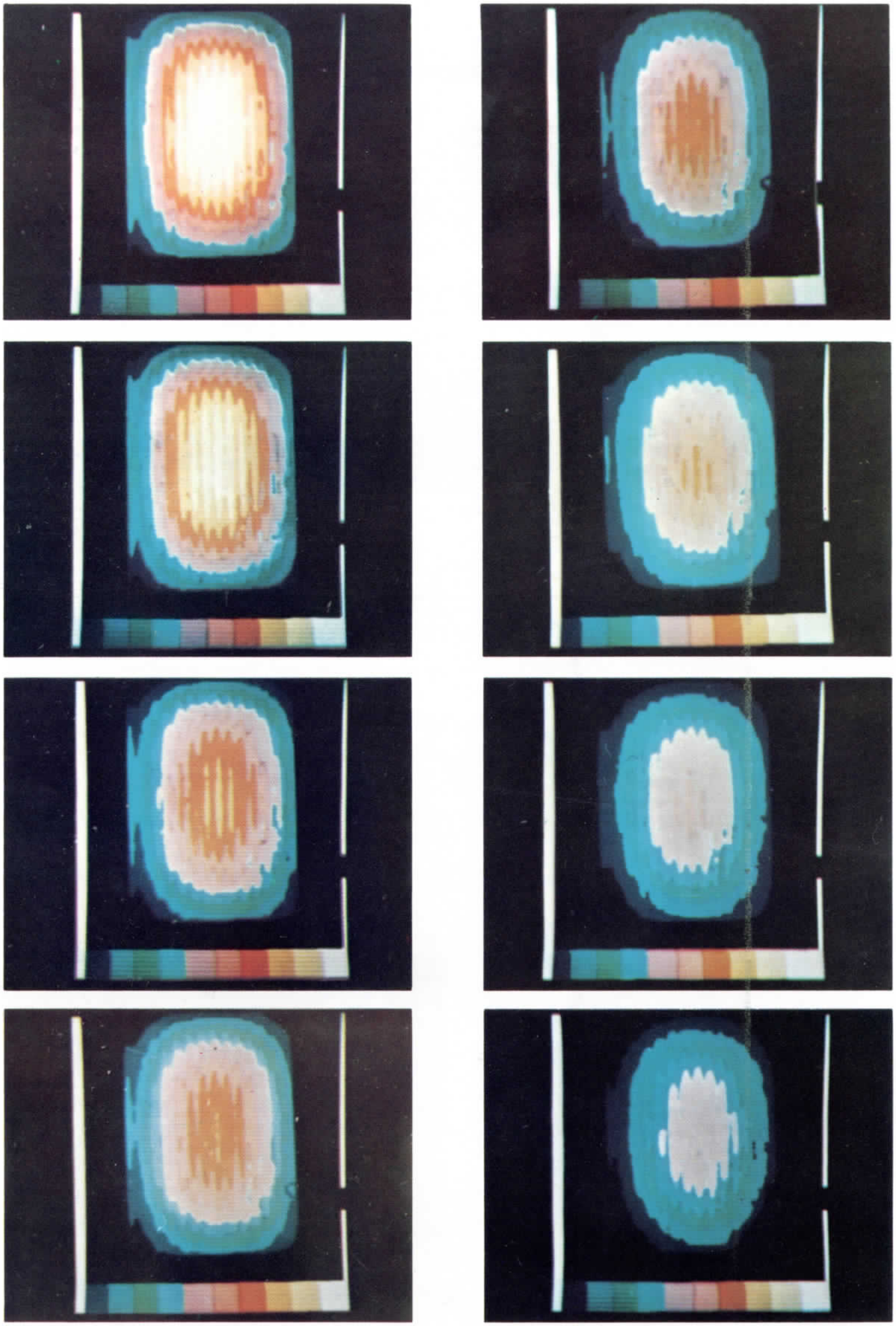


FIGURE 11 This series of themoraphs show the progressive thermal patterns on the surface of a cooling ingot.

bution on a plate mill slab just after a first scale-breaking pass. The cooler area where the slab rested on a furnace skid is visible at the left of the image, and higher temperature areas appear at the leading edge. Individual steps of temperature are 45 degrees F (25C), and the center-scale temperature is about 2000 F (1093 C). Dimensions of the finished plate are dependent to a large extent on the temperature distribution in the slab leaving the furnace, as most hot strip mill operators know, who have long been aware of the "skid marks" visible both in the pyrometer charts and the gage charts alike. The fixed pyrometer is a valuable control tool, but it reads temperature in a narrow line along the slab as the slab moves by the sensor. The thermal image is able to present temperature distribution end-to-end and edge-to-edge nearly instantaneously.

A similar display is shown in Figure 11, which shows a series of thermal images of a cooling ingot. The ingot mold was stripped from the ingot, and successive thermal images were taken so that a total of 8 thermal images during the cooling of the ingot have been recorded. Pattern of temperature is about as expected; the hot area is in the center of the broad face of the ingot and this relationship of high to low temperature maintains during the observation of its cooling. The patterns shown here are helping with construction of a mathematical model of ingot cooling and reheating.

An interesting application was the display of the heat-affected zone adjacent to an electroslag weld. The welding set-up is shown in Figure 12. Two plates, 2-inches thick, are positioned with the vertical electroslag weld channel between them. As the reaction is started, the heat-affected zone starts to spread out horizontally from the hot welding area. Thermographs of the progress of this weld are shown in Figure 13. The thermal image help locate thermocouples for successive tests of this welding technique.

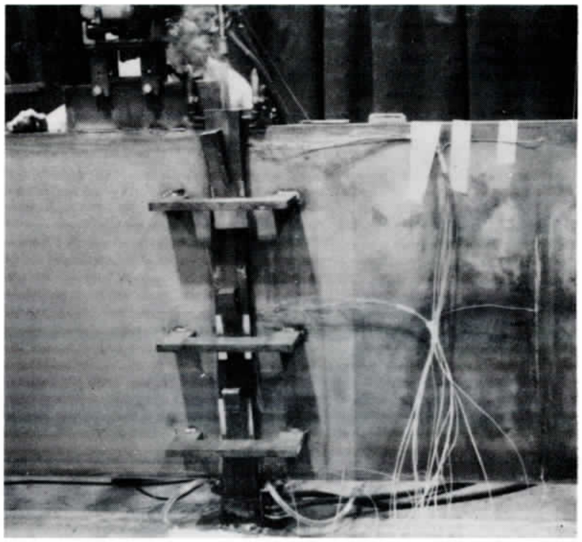


FIGURE 12 Photograph of electroslag welding experiment. The vertical channel will contain the weld area. Wire are to thermocouples.

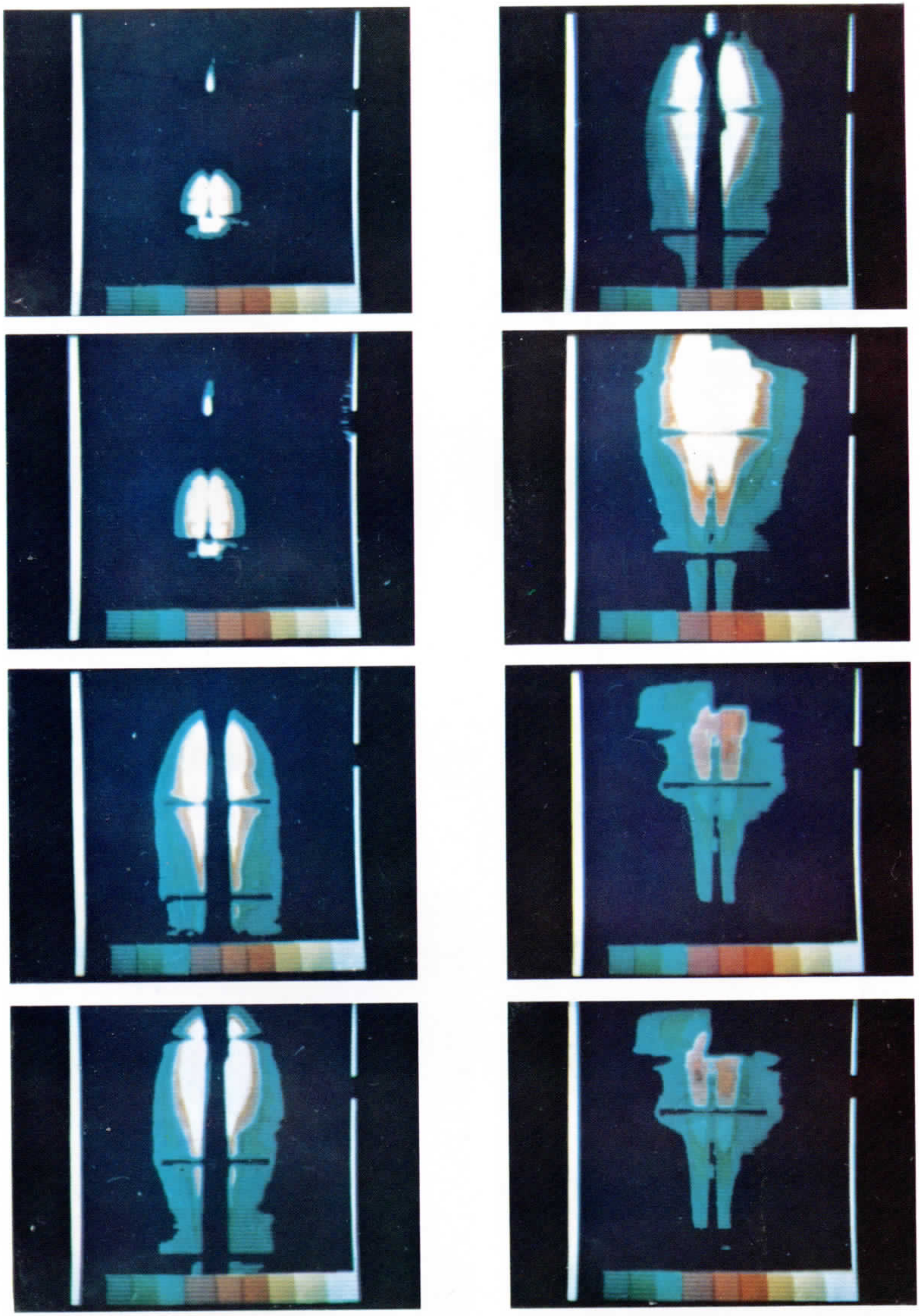


FIGURE 13 Series of thermographs showing progress of thermal pattern spreading away from the electroslag weld as the welding progresses.

Distribution of temperature on the outer shell of refractory-lined vessels indicates relative heat flow rate from the vessel; high temperature indicates a high heat-loss rate. Local temperature may be higher than average surroundings due to thin refractory lining, or may be lower due to a build-up such as a scab on a blast furnace lining, or a poor bond between refractory and a vessel shell.

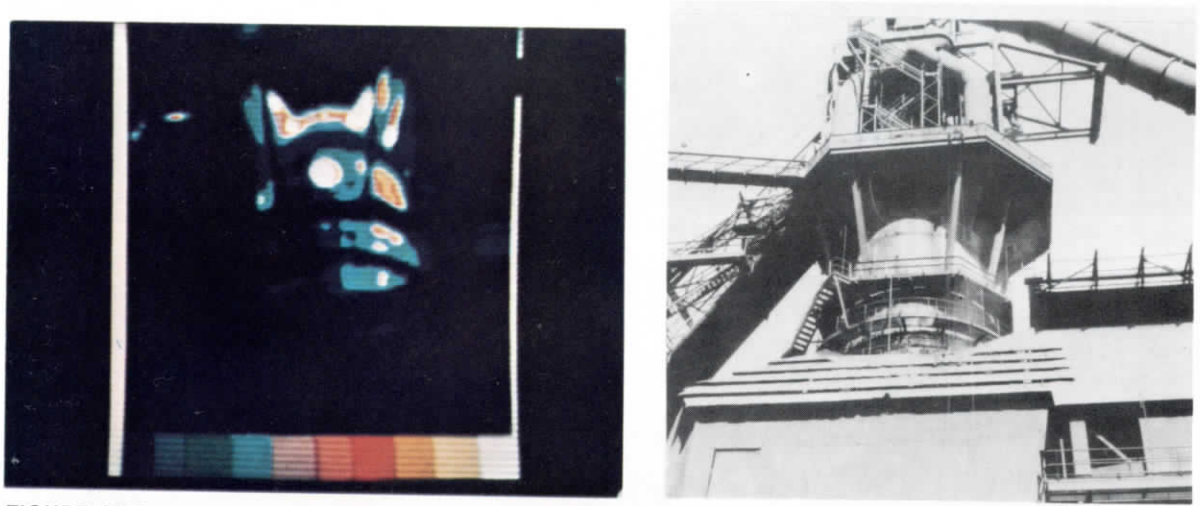


FIGURE 14 Photograph and thermograph of blast furnace stack showing higher temperature area caused by worn lining.

U.S. Steel's blast furnace operators have used thermal imaging to help them diagnose troubles with furnaces, stoves, and hot metal ladles. Figure 14 shows a photograph of a blast furnace, together with a thermograph of the furnace that shows a higher temperature area. The operators knew of its existence and had placed temporary cooling sprays until such time as the lining could be patched. The thermal image verified the extent of the area and pointed out to the operators that the cooling sprays were placed too far to one side. The operators relocated the sprays. Figure 15 is of blast furnace stoves, taken to see whether or not there were abnormally hot areas on the stoves. We have been doing extensive surveys of the surface temperature distribution on submarine hot metal cars. Figure 16 shows the temperature distribution along a series of pictures that shows the growth in higher temperature areas on a ladle car over a period of three months. U.S. Steel is applying this technique to a study of temperature changes in ladle cars, and will attempt to relate this to refractory lining thickness and to explore methods of temperature measurement that will attain maximum lining life consistent with operating safety. Figure 18 shows a thermal image taken on a hot blast main to examine areas around refractory joints.

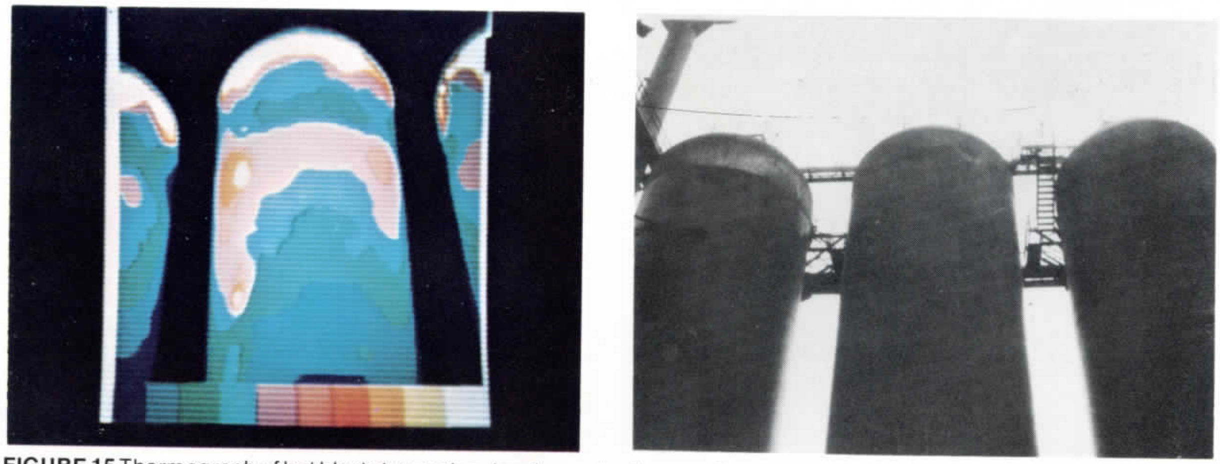


FIGURE 15 Thermograph of hot blast stoves showing thermal pattern on the stove shells.

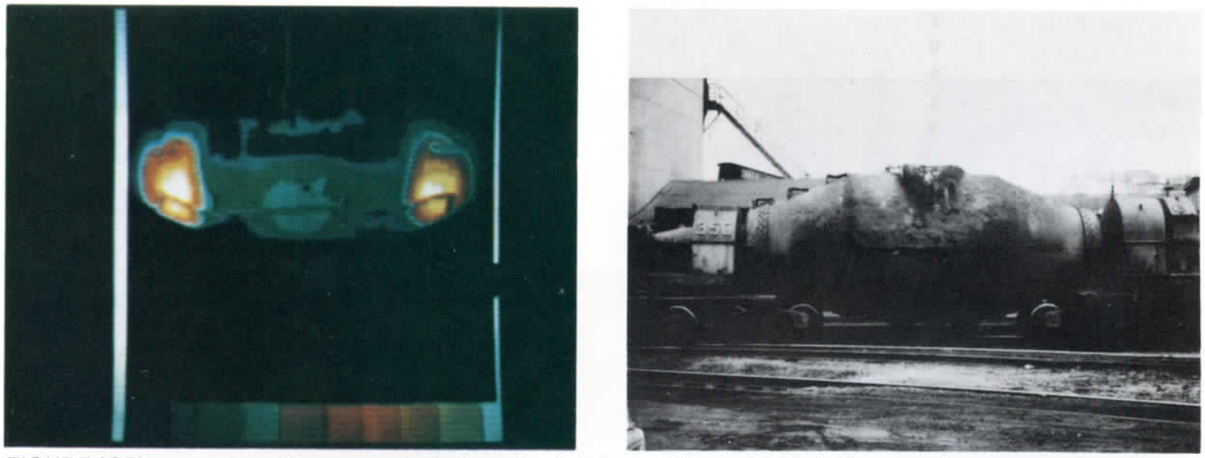


FIGURE 16 Photograph and thermograph of submarine-type hot metal car, showin hotter areas in reds and yellows.

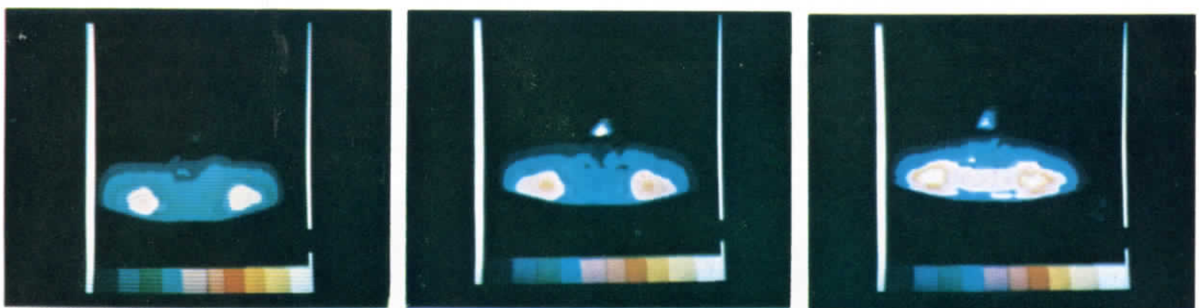


FIGURE 17 Three thermographs taken a month apart, showing the progressive growth of hotter area on asingle hot metal car.

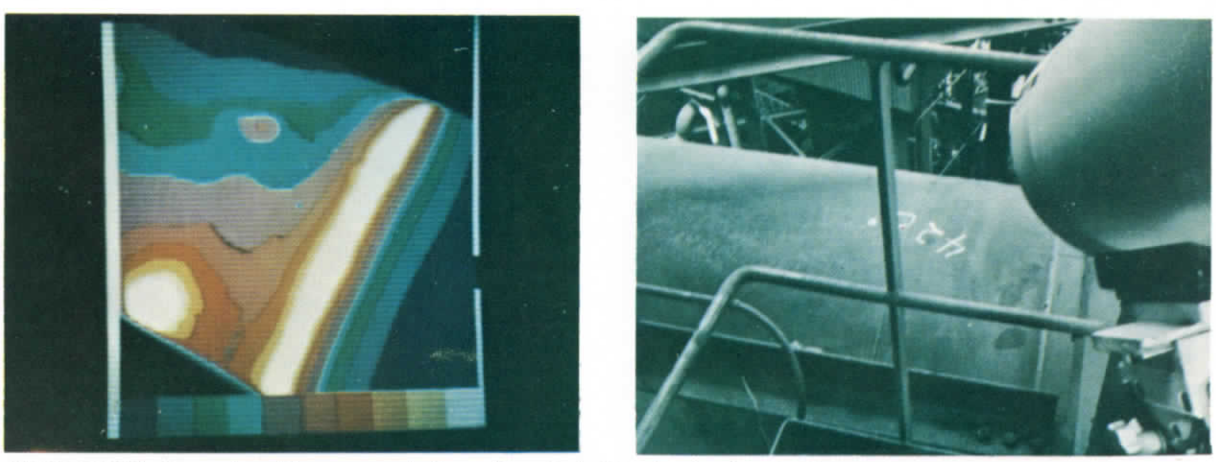


FIGURE 18 Photograph and thermograph of a portion of a hot blast main, showing thermal pattern.

Another useful furnace application is shown in Figure 19's thermal image of a recuperator on a reheat furnace at one of our plants. The furnaces preheat air temperature was not as high as design standards; an initial phase of a study to improve efficiency was to take a series of thermograms of the preheat air system. Air is preheated in a bank of horizontal stainless and refractory tubes called a recuperator. Hot flue gas passes around the outside of the tubes on its way to the chimney; combustion air is drawn through the hot tubes and is discharged into the gas burner. The intake ends of the tubes are open to atmosphere, and they discharge into a plenum chamber from which air is drawn for the gas burner. The thermograph shows the ends of the tubes, hotter where exhaust gases enter the stack at the left, and gradually colder toward the exhaust gas discharge flue. Plant operators plan to make changes that will raise temperature of the intake air.

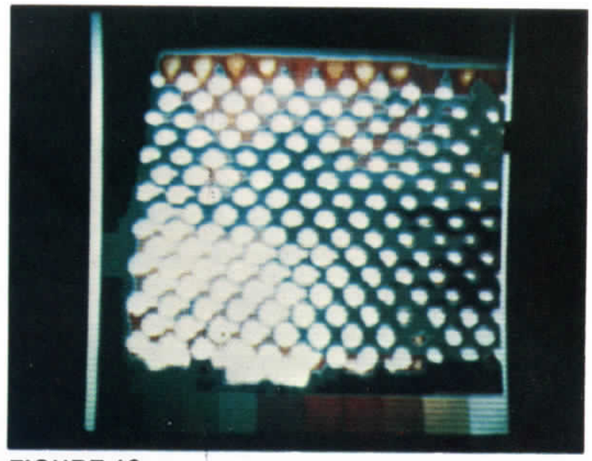


FIGURE 19

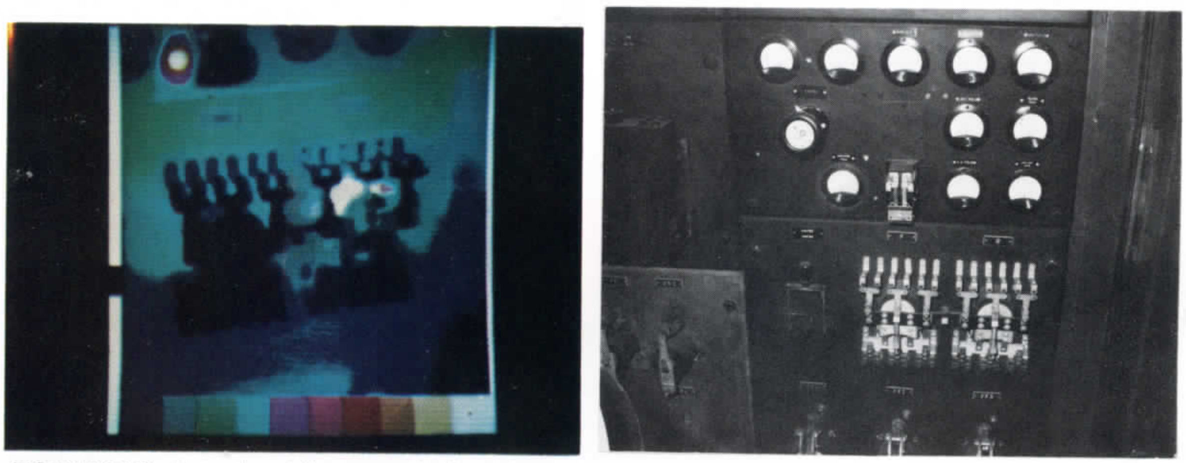


FIGURE 20 Photograph and thermograph of relay panel in mill electrical area. Overheated components are easy to find.

A major use of thermal imaging has been in the preventive maintenance on electrical and mechanical equipment, particularly in power distribution. It can identify the one hot wire in a bundle of cables to help trace faults, or show the distribution of temperature in the myriad coils on a relay-filled control board in a motor room as shown in Figure 20. For several years power companies have been using routine thermal image scans of switchgear and tie points to detect incipient fault development so that maintenance can be scheduled to prevent interruption of service. A tie point whose temperature has risen above normal, for instance, is an indication of incipient failure, as shown in Figure 21. In an early experiment a hot tie point was noticed in a 440 volt distribution system 20 feet overhead. That this tie point burned through some 20 hours later helped to establish the validity of thermal imaging in electrical preventive maintenance.

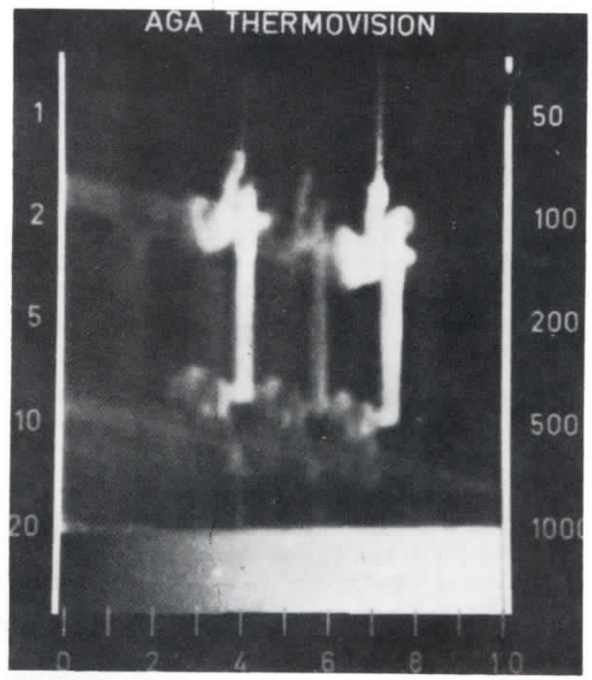


FIGURE 21 Thermograph of disconnect switch in power grid; the two hots links are clearly shown. (Courtesy of Davey Infrared Systems)

A major factor in the usefulness of thermal imaging in electrical systems is that measurements are made without contact, and can be made from a considerable distance, so that temperatures can be measured at operating loads and potentials. This characteristic was most helpful in U.S. Steel's study of heating in electric furnace mast arms, Figure 22. Serious problems were encountered with high current (up to 95,000 amperes) inductive heating of certain components in the carbon-steel electrode mast assemblies of a 200-ton electric arc-furnaces. Thermal images quickly located areas of overheating and gave continued, qualitative temperature distribution pictures during design changes that eliminated the problem.

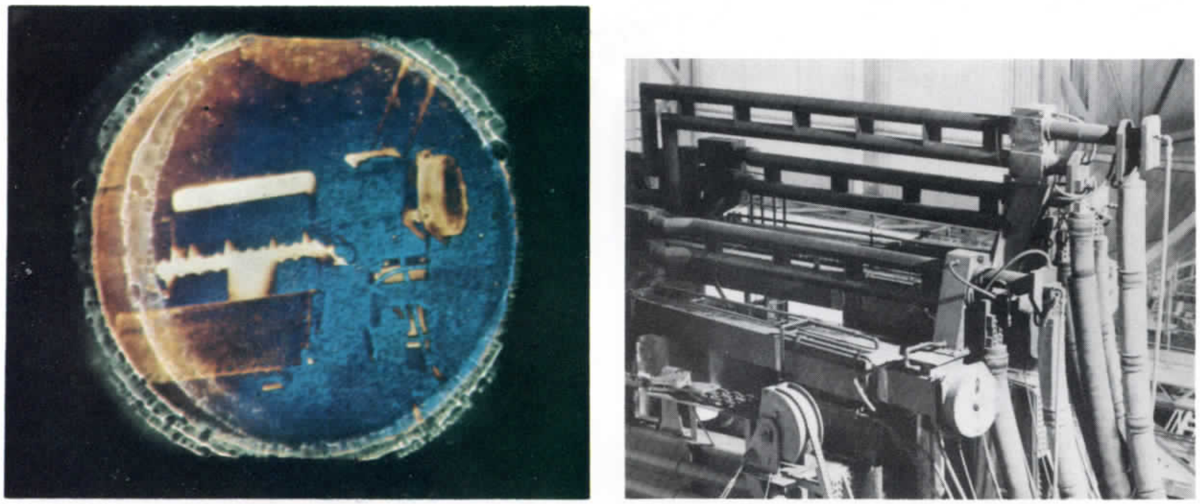
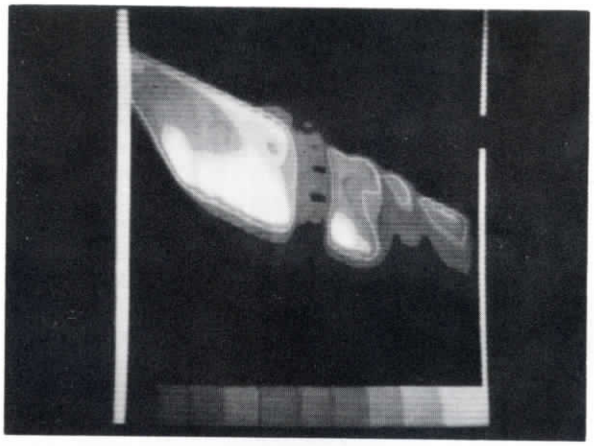


FIGURE 22 Photograph and thermograph of electric furnace mast arms made during studies of mast-arm heating on new high-current electric furnaces. The thermograph was made by an instrument named the Evaporograph, formerly made by the Baird Atomic Company.

Thermal imaging has considerable use in diagnosing problems in ducts and process piping. Consider gas ducts, Figure 23. Gases go through the duct and as often as not deposit sludge on the bottom of the duct. The sludge buildup acts as something of an insulator; the temperature of the duct that is covered by sludge will be different from that where the walls are bare. A thermal image of such a duct locates the extent and distribution of deposits that have settled on the bottom. (This, of course, holds true only if the gases traveling through the duct are sufficiently colder or hotter than the ambient surroundings.) One of the more interesting images is that of a tar storage tank, Figure 24. The tar is stored hot to keep it fluid, and this image of the tank shows a most interesting situation. The warm band is about 2° F higher than the surroundings, and is due to freshly pumped warm tar. The white area on the right-hand fifth of the image is due to sunlight warming the surface; a similar effect on the adjacent tank is easy to see; the shadow cast by the right-hand tank is visible as a blue area, and sunlit area appears magenta. Steam lines show white, and the hot gases from a distant stack show as a white puff over the top of the left-hand tank.

A very difficult thermal imaging job was the diagnosis of temperature distribution on a coke oven gooseneck, a casting that couples the riser from the end of a single coke oven to the collection main that goes along the sides of the entire battery of ovens, as shown in Figure 25. The gases given off by the coal in the oven travel up through the riser, around the gooseneck and into the collection main. During operations at a coke plant, it was noticed that some goosenecks were overheating, apparently, and were cracking. Attempts to measure the temperatures with temperature-indicating crayons were unsuccessful. A thermal imaging unit was mounted with a clear view of the gooseneck, and Polaroid pictures were taken during the critical part of the heating just as fast as operators could pull the tabs out of the film pack, Figure 26. These time series of temperature distribution proved most illuminating; thermocouples were placed at locations indicated by the thermograms, and subsequent thermal studies of temperature transients showed the problem of the deterioration and how to overcome it.



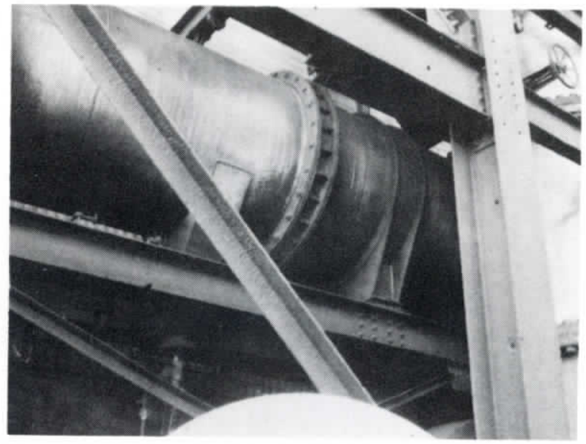


FIGURE 23 Photograph and thermograph of ducts in coke oven area. Distribution of temperature on duct surface will indicate degree of sludge deposit in duct, provided that gas temperature is different from ambient temperature.

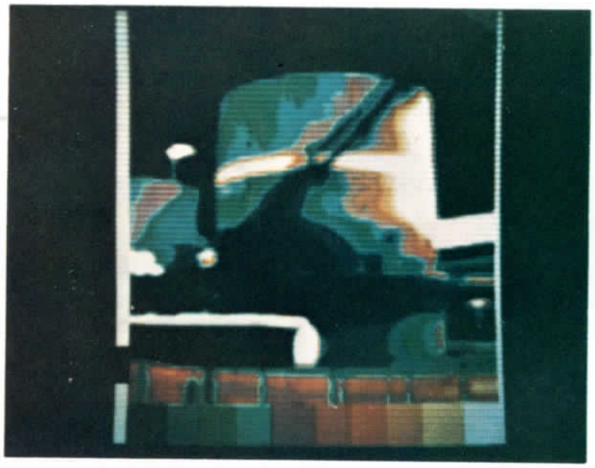


FIGURE 24 Photograph and thermograph of tar storage tank. The light band represents hot tar resting on cooler matter, presumably sludge. The lighter area at the right-hand side indicates that hot fluid flows down to drain at bottom of tank.

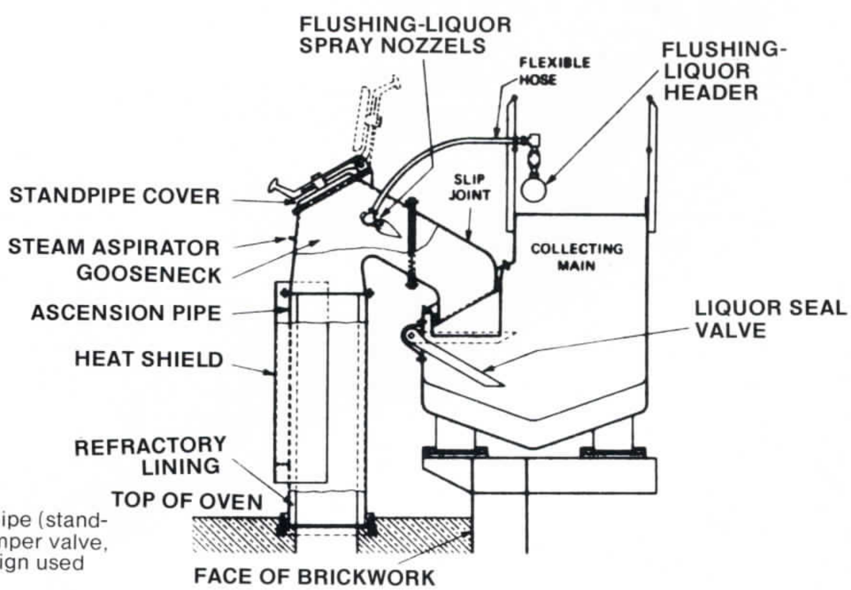


FIGURE 25 Section through an ascention pipe (standpipe), elbow (gooseneck), liquid-sealed damper valve, and collecting main of a typical off-take design used by Koppers Company.

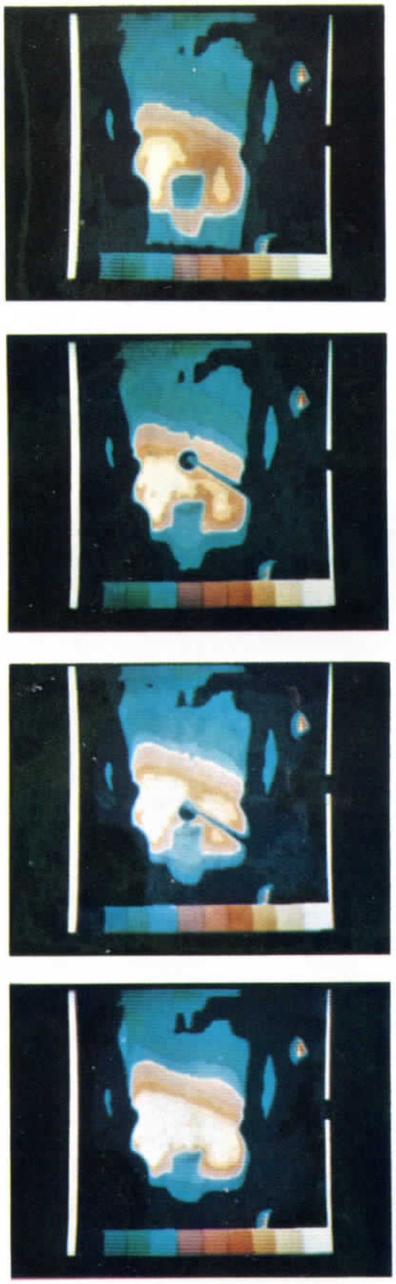


FIGURE 26 Thermographs of rapidly changing heat pattern on gooseneck castings at coke oven battery.

We have shown a few of the uses to which U.S. Steel is putting thermal imaging to help solve problems in processing and equipment maintenance in plants. The thermal imaging system is based at the Research Laboratory and is operated by a specialized photoinstrumentation group as part of their assignment both in the laboratory and in the plants. We do not belive that equipment of this kind can be effectively lent to and used by persons not experienced in its care and operation. A number of seminars have been held at the plants to acquaint operators and maintenance people with the potential usefulness of thermal imaging in their areas. As the capabilities of this system have become better known in the plants, their requests for the service have expanded, and we expect that this expansion will continue. We believe that the thermal imaging system has been a good investment for U.S. Steel.

A SIMPLIFIED APPROACH TO QUANTITATIVE ESTIMATION OF REFRACTORY LINING THICKNESS ON CERTAIN VESSELS

Rutger Johansson
Market Project Manager, Steel
AGA Infrared Systems AB
Lidingö, Sweden

INTRODUCTION

The steel industry with its temperature related problems and hazardous working environment has always been considered a suitable area for the use of remote sensing instruments for temperature measurements as a part of plant condition monitoring programs, NDT-operations, etc.

This method; Thermography, is a technique for extending the vision beyond the normal confines of the visible spectrum into the infrared, but not only permits vision in the infrared but also quantifies that picture in terms of actual temperature variations.

Thermography is different from other methods in that it permits rapid surveillance of large industrial installations without, or with very little, interference with the normal operation of the plant.

Considerable advances have been made in the last years in the interpretation and analysing of heat pictures obtained but the rapidly growing use of this technique is also very much dependant on advanced instrumentation.

THE INFRARED CAMERA

The first commercial infrared scanners were designed merely to obtain an image, however, for most NDT- or plant monitoring applications this detection capability was not enough and therefore very soon different features for quantitative temperature measurements were incorporated.

Early systems were very often cumbersome to use around the plant and mostly confined to laboratories. It was not until the introduction of the AGA Thermovision Model 750 the use of thermography for plant condition monitoring became a practical reality.

Today this highly portable instrument is used by more steel companies around the world than any other and contributing to a more profitable business and a safer working environment.

The portable AGA Thermovision Model 750 (see Figure 1) can detect temperature increases or differences as small as 0.2° but the degree of detection decreases slightly as the temperature increases. The scanning rate is 25 picture frames per second thus giving a flicker free presentation on the display monitor.

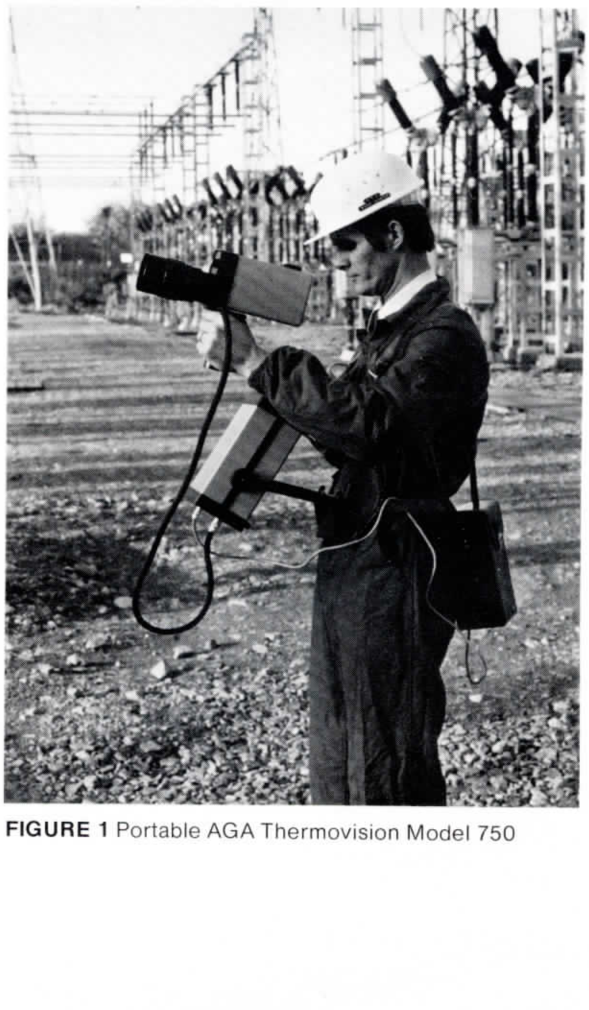


FIGURE 1 Portable AGA Thermovision Model 750

The instrument converts the invisible energy from the object to a visible picture, a thermogram (see Figure 2), where the routine optimum technique is a black and white or gray tone image.

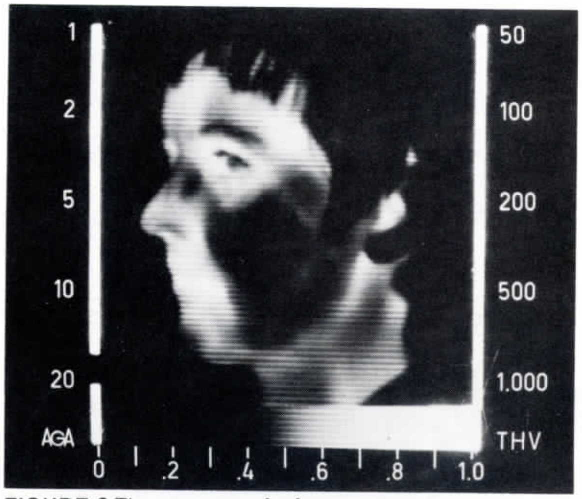


FIGURE 2 Thermogram of a face

A standard feature is the possibility of thermal enhancement with the use of isotherm markers which appear as saturated white levels. The live picture on the screen can be recorded by utilizing a Polaroid camera.

For fast dynamic studies when photographic techniques are not suitable, instrument tape recorders can be utilized.

ABSOLUTE TEMPERATURE MEASUREMENTS

The purpose of this section is to present a review of the more practical aspects of absolute temperature measurements.

The parameters of greatest interest in thermography measurements are temperature and emissivity and either of these two object parameters can be determined when the other is known, given the availability of a reference source of known temperature and emissivity. Formulas have therefore been derived for calculating the true object temperature from the isotherm marker read outs, taking into account the emissivity if this is known or for calculating the value of the emissivity if the temperature is known. (see Figure 3)

Basic formula for determing isotherm value I_o for true temperature of object when object emissivity ϵ_o, reference temperature T_r and reference emissivity ϵ_r are known.

$$I_o = \frac{\Delta i_{or}}{\epsilon_o} + \frac{\epsilon_r}{\epsilon_o} I_r + \left(1 - \frac{\epsilon_r}{\epsilon_r}\right) I_a$$

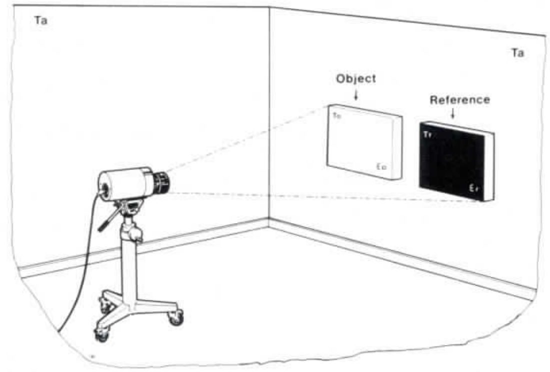


FIGURE 3 Principle of absolute temperature measurements

It becomes obvious that a special reference or an object with known temperature must be used. For practical purposes this can be an easily identified part of the installation itself where the temperature initially is determined by using a contact thermometer or, if the temperature expected is within 100-150° C and the ambient temperature not too low, the face of a person which under normal circumstances has a fairly well-known temperature.

The emissivity factor for both the reference and the object studied must be determined when absolute temperatures are measured. However, the oxidized mild steel surfaces usually encountered on various sections of a plant have a fairly constant emissivity factor and present no major problem in obtaining a good thermal temperature.

Available now are programs for Hewlett Packard Mod. 65 programmable calculator allowing the absolute temperature, with corrections, to be calculated.

ONE DIMENSIONAL STEADY STATE HEAT FLOW THROUGH SANDWICH STRUCTURES

The main problem and the reason for making thermal surveys of a steel plant is very often to estimate the progressive deterioration of the internal surface of a sandwich structure in a sealed system. (Ex. steel/thermal insulation refractory)

Initial assumptions;

- Thermal contact resistance at the refractory steel interface will be taken as zero
- The internal face of the refractory is at the internal fluid temperature
- Thermal contact resistance between each different layer in the wall will be taken as zero

In the steady state situation the quantity of heat flowing per second through unit area of wall, steel/thermal insulation/refractory brick given by:

$$\frac{T_i - T_s}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}} = h\,(T_s - T_a) + \epsilon_o \sigma \left[(T_s + 273)^4 - (T_a + 273)^4\right]$$

Where:

$\frac{\delta}{\lambda}$ is the ratio of material thickness to corresponding thermal conductivity for each layer

T_i is the internal surface temperature

T_s is the external surface temperature

T_a is the ambient temperature

h is the steel/air heat transfer coefficient

ϵ is the emissivity of the steel surface

σ is the Stefan-Boltzmann constant

Using this equation it is a simple matter to calculate the variations of T_S with thickness of refractory. It is furthermore simple to establish certain critical temperature levels for an installation (This is further discussed in the example later in this paper).

The method described offers a very fast simple technique which can be used to monitor wear trends but it must be remembered that this interpretation is based on elementary considerations and the situation in practice is frequently complicated by the presence of an airgap between the different structural layers, cracking of the refractory brick work, and the occasional loss of refractory in bulk instead of the assumed steady erosion.

DETERMINATION OF LININING THICKNESS ON STOVES

The following example is taken from the case book of an AGA Thermovision user. Although certain information has, for reasons of secrecy, been omitted this example clearly shows the usefulness of the method.

The middle stove in a set of three (see Figure 4) has been noticed to be overheating and refractory bricks had been found on the bottom of the stove.

FIGURE 4 Visual Photograph of three stoves.

Waterspraying had been started but it was necessary to decide if the stove could be kept in operation until a suitable date or if it had to be shut down immediately for repair.

It was decided that a thermographic survey should be carried out.

The waterspraying in operation on the overheated area was stopped and the shell of the stove allowed to reach its steady state operating temperature. Throughout the inspection, stove surface temperature varied insignificantly, from which it was concluded that the heat capacity of the stove walls was sufficient to mask out fluctuations in internal themperature as a result of the stove being run alternatively 'on-blast' and 'on-gas'.

On one of the resulting thermograms (see Figure 5) a hot area could be found up near the dome.

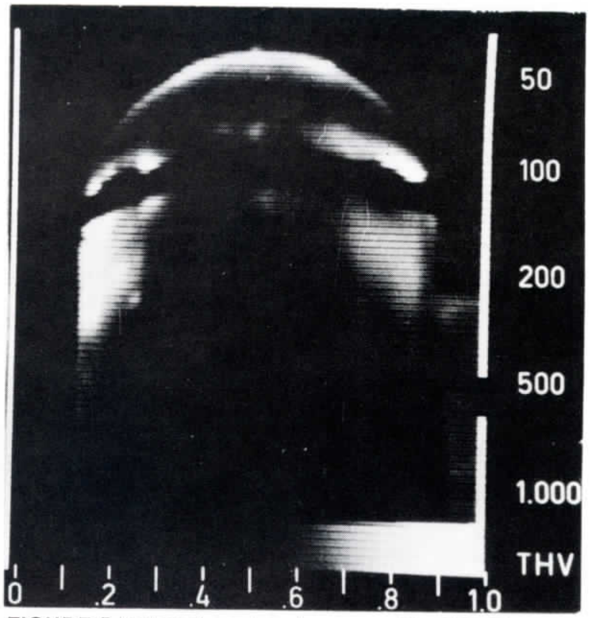


FIGURE 5 Hot spot on stove (measured to 150° C)

By using the isotherm function and the sky as a reference an absolute temperature level of 150° C could be determined.

Since different surface temperatures represent different thickness of refractory the decreasing thickness of refractory with resulting variations in surface temperature could be calculated using the previously described formulas (see Figure 6).

Such diagrams are only applicable to one particular design and the material used and sometimes only to one section of a furnace.

In this case it was decided that the stove could be operated but under surveillance and under continuous waterspraying up to a planned repair date some three months later despite the total loss of refractory with the insulation layer fully exposed. The diagnosis was confirmed when the stove was closed for repair.

In a case like this, the obvious benefits from a thermographic survey is not only the knowledge and extent of a damage to a wall allowing decisions of continuous operation to be made but also to give time to prepare and arrange material for the repair.

The method described can be used to, in advance, establish certain temperature levels for critical wear patterns with one level indicating the need for regular surveillance and the next level indicating the need for immediate corrective actions or further investigations.

A stove has been selected as an example but quantitative estimation of refractory in other vessels used in an iron and steel plant is a routine operation by a number of AGA Thermovision users.

THE USE OF HP-65 PROGRAMMABLE CALCULATORS FOR LINING ESTIMATION

The Hewlett Packard programmable calculator Model HP-65 is using programs which are prerecorded on magnetic cards. Knowledge of programming the HP-65 is not required for wall thickness estimation but familiarity with the operation as described in the owners handbook is essential.

The method, for calculation of surface temperature with reduced wall thickness, previously described in this paper, can be somewhat involved if no computers or programmable calculators are used. For the HP-65, used with AGA Thermovision for absolute temperature calculation, are prepared and presently under final test programs for lining thickness estimation.

This programs will allow, in the basic form, the outside wall temperature to simply calculated for;

- An intact multilayer structure

  or

- A critical wear situation requiring further investigations

  or

- A critical/dangerous wear situation requiring immediate remedial actions.

By repeated program runs enough data for a diagram like Figure 6 can also be obtained.

For each wall calculation the following data must first be obtained.

- Furnace inside temperature (T_i)
- Ambient temperature (T_a)
- Outside wind velocity (in meter/second)
- Surface emissivity (ϵ)
- Number of layers in the wall
- For each layer:
  - Initial thickness
  - Coefficient of thermal conductivity
- Eventual airgaps between layers.

Once entered into the calculator the program will calculate the outside wall temperature as well as the temperature between different lavers.

By altering the input data different situations or wear patterns can be simulated.

The same restrictions or limitations applies as to the manual method previously described.

SUMMARY

Numerous aspects of steel making have been studied with the AGA Thermovision. The few examples in this paper only give a hint of the vast possibilities of using an infrared scanner as a tool for solving problems. The introduction of small computers or programmable calculators like the HP-65 makes the necessary calculations simple and understandable by everybody without specialized training or education.

However, in order to gain the maximum benefits from a thermographic survey, regular inspections of the plant is required to confirm validity of the analyses and then accurately establish the thermal picture versus wear patterns as well as predictions regarding failure and the need for maintenance.

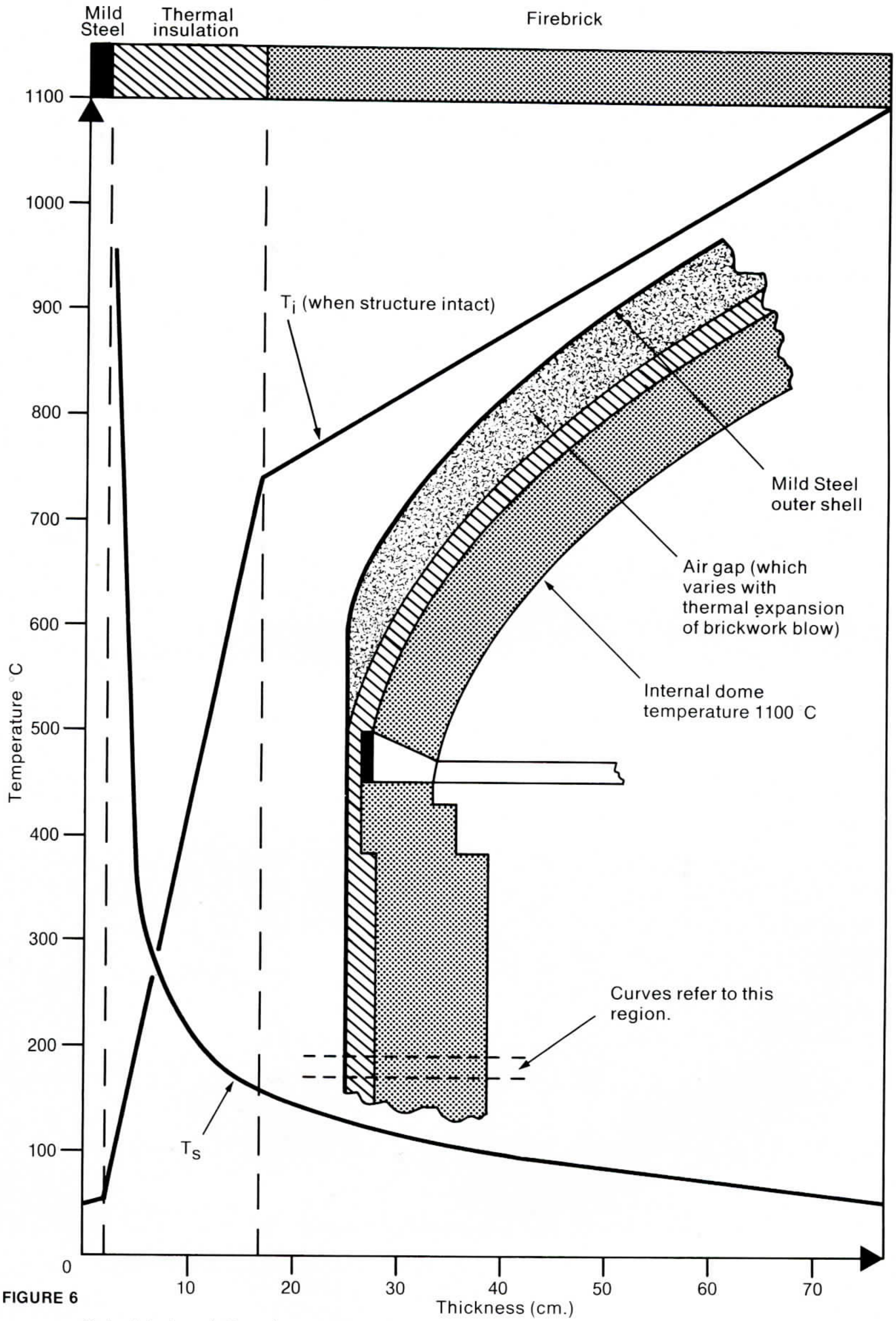


FIGURE 6

Calculated variation of external surface temperature (T_S) with decreasing thickness of refractory for a blast furnace stove. The variation of internal temperature (T_i) for the intact structure is also shown. Structural details are given in the insert.

THERMOVISION MONITORING OF STEEL REFINING VESSELS

Arthur M. Brandenburg
Technical Specialist
Manufacturing and Applications Engineering
Colt Industry, Crucible Steel
Pittsburgh, Pennsylvania

INTRODUCTION

The analysis of thermal patterns has become an increasingly valuable testing technique for industrial applications. In the steel industry the infrared thermal scanner has rapidly developed as a nondestructive testing tool. Our own experience with the AGA Thermovision during the past eight years has exposed to us some of the potential applications that exist in research and development, quality control, and preventive maintenance areas of Specialty steel manufacturing.

Since our first experiments with the AGA Thermovision in early 1969, the equipment design has been steadily improved to include the special aspects needed for steel production applications. During those initial trials of the Thermovision we were rather dramatically exposed to its potential in obtaining heat patterns with a color thermograph of a portion of an oxygen steel refining vessel.

Figure 1 demonstrates a comparison of conventional photography to the differential black to white configuration presented by the Thermovision. It also reflects the enhanced temperature resolution obtained by the use of color bands to display a heat map of the vessel surface. The color bands or isotherms represent 30°F and the temperature range from dark blue to white represents 210°F.

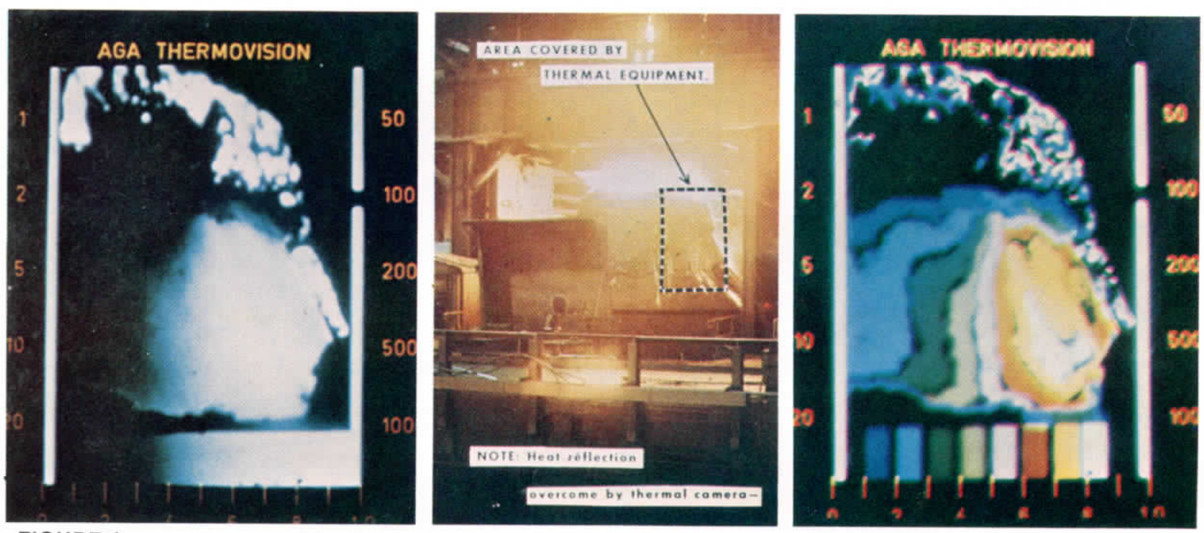


FIGURE 1

We have on several occasions used the Thermovision for specific projects in Research and Development, the most recent being the determination of temperature variations on the surface of a steel refining vessel.

MONITORING THE AOD VESSEL

Late in 1974 our Stainless Division requested assistance in measuring surface temperature variations on the vessel used in the Argon-Oxygen-Decarburization process at our Midland location. After considering various techniques such as thermocouples, contact pyrometer, and infrared, non-contact thermometers, it was decided to use the AGA Thermovision unit. The initial advantages influencing this selection included the results obtained earlier in the oxygen refining vessel thermographs and the requirement to observe from a distance the manipulation of the AOD vessel during processing. The portable Thermovision 750 was selcted for the study due to its capability for remote and continuous thermal monitoring Through the slave connection of the color monitor, variations in temperature over the shell surface were presented as isotherm color contours. These real-time color patterns were periodically photographed for subsequent analysis.

To obtain an unobstructed view of the vessel the instrument was positioned on a platform ten feet above ground level directly in front of the vessel at a distance of approximately 75 feet. On the average, eight photographs were taken during each heat over a period of two complete campaigns. The thermographs shown here all display the tilt-back position. These photographs are representative of the general thermal patterns throughout the survey.

EXAMPLES

The thermographs used as examples are color isotherm patterns of surface temperature variations during Heats No. 7 and No. 15 processed on consecutive days during one campaign.

Figure No. 2 identified as 2 and 7, taken during the course of Heat No. 7, display an isotherm pattern on the vessel surface representing a temperature range of 184 degrees F. The coolest area (dark green) at the base is 328 to 376°F and the warmest areas (orange) reaches 512° F. The various bands represent the following temperatures:

Orange	489 - 512°F (23°)
Red	465 - 489°F (24°)
Magenta	440 - 465°F (25°)
Purple	411 - 440°F (29°)
Lkght Green	376 - 411°F (35°)
Dark Green	328 - 376°F (48°)

It is evident that very little change took place during this 28 minute span. The basic pattern remains the same with some increase in temperature on the left-top and a decrease just to the right of center. These changes represent a minimum of a few degrees or at the most 47° F.

NOTE:

This calibration curve (Figure 3) was taken from the equipment instruction manual. Temperatures were established for these heats using a contact pyrometer temperature of 500° F in the orange area as a known reference. The equipment settings established 450 isotherm units for full spread or 45 units per color band. By projecting to temperature through the curve for f-stops of 5.1 the color bands were established for these temperatures.

White	533 - 550°F (17)
Yellow	512 - 533°F (21)
Orange	489 - 512°F (23)
Red	465 - 489°F (24)
Magenta	440 - 465°F (25)
Purple	411 - 440°F (29)
Light Green	376 - 411°F (35)
Dark Green	328 - 376°F (48)
Light Blue	258 - 328°F (70)
Dark Blue	32 - 258°F (126)

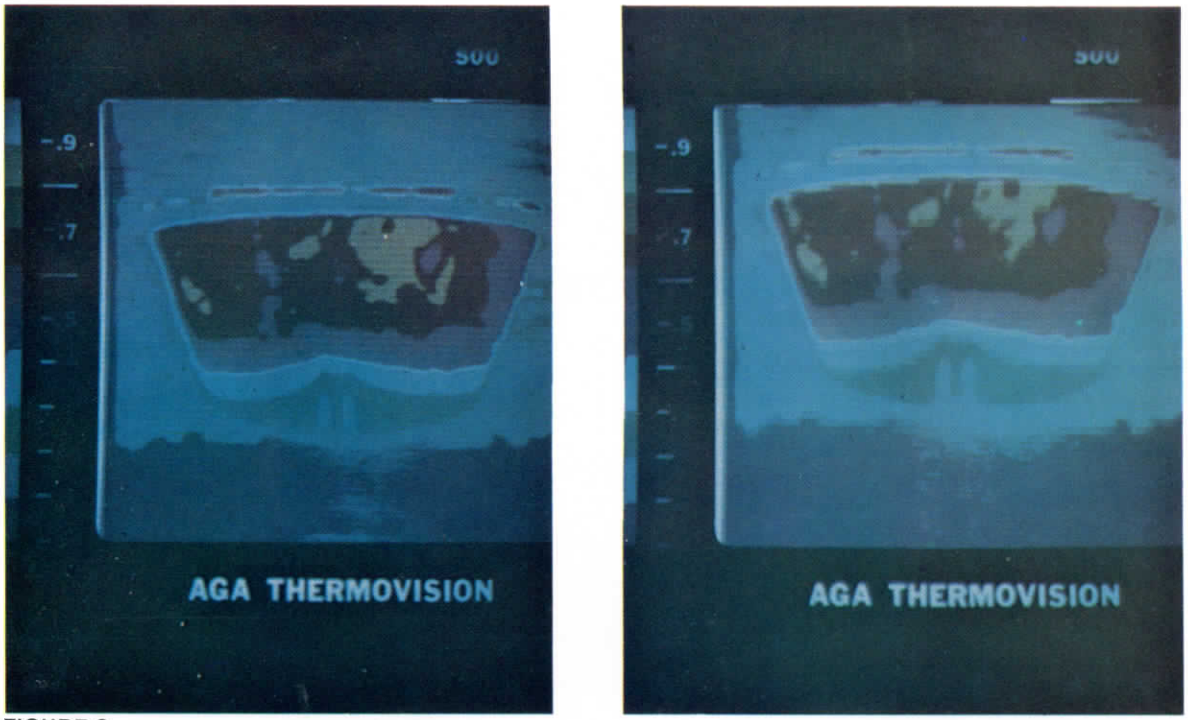


FIGURE 2 2 7

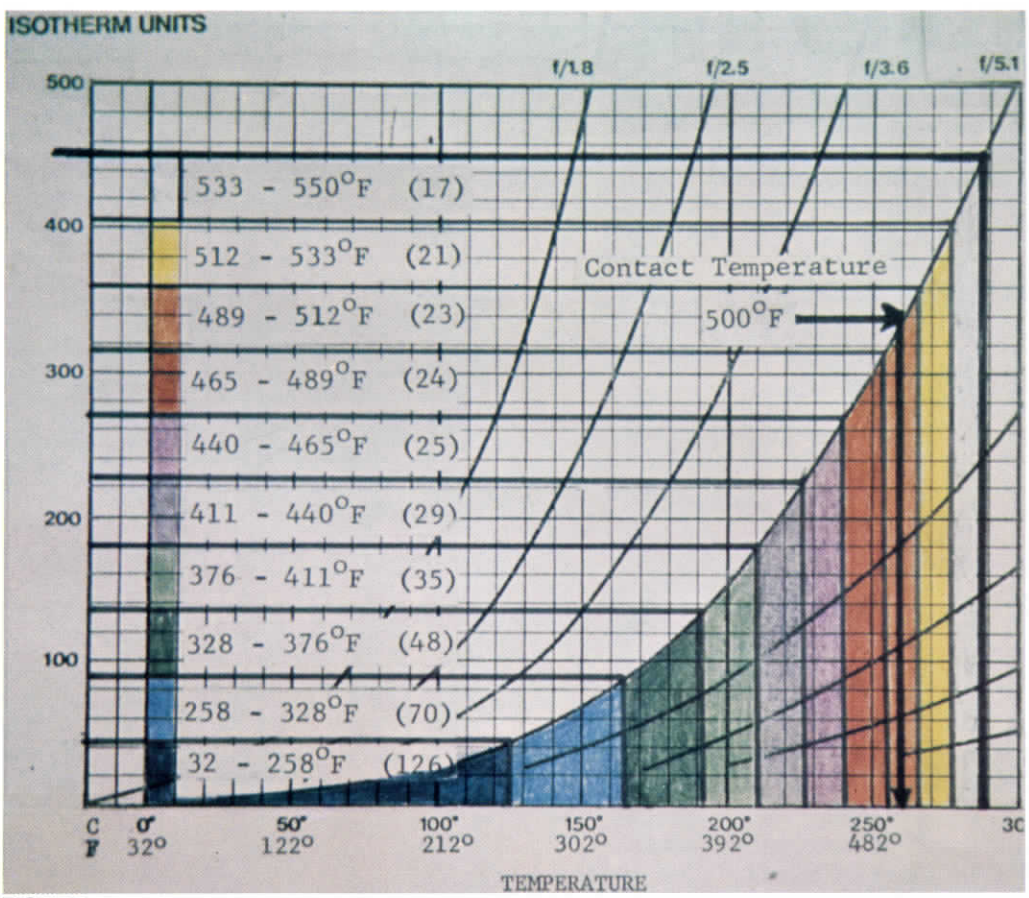


FIGURE 3

TYPICAL CALIBRATION CURVE

Figure 4 identified as E and A were taken during Heat No. 15 and show a heat pattern on the surface representing a temperature range of 205 degrees F. the coolest area (dark green) at the base is 328 to 376° F and the warmest area (yellow) reached 533° F. the bands represent the temperatures displayed on the color calibration chart.

A small change in temperature occurring in the 37 minute period can be detected on the left center portion of the vessel as an increase in yellow area. Again there is no evidence of change to the basic heat pattern.

The contrast of temperature distribution on the vessel surface is demonstrated by picture X2 (Heat No. 7) and H (Heat No. 15) (Figure 5). A shift upward of approximately 40° F appears to have occurred in the warmer regions, 440° F and above. The magenta band of Heat No. 7 has been replaced by red and most of the orange band in Heat No. 15; a temperature increase of 25 to 50° F. The large red area of Heat No. 7 has shifted to yellow in Heat No. 15, representing an increase of approximately 25° F. In Heat No. 7 the temperature range was 184° F while Heat No. 15 it was 205° F. Heat patterns generally conformed to these same basic patterns throughout the study.

SUMMARY

The data presented are intended to provide thermal patterns representing temperature variations on the vessel surface. To date, there has been no correlation of changes in vessel surface temperatures to changes in internal vessel temperatures. We antiticate it to be a contributing factor together with dwell time, vessel manipulation and refractory wear. A detailed analysis of these elements and the accumulated color-therographs is presently underway.

CLOSING STATEMENT

We have attempted to demonstrate one of the many applications for infrared imaging in the steel industry. The initial review of this data and that collected during other projects indicates the Thermovision to be a valuable diagnostic tool for research use in various steel mill applications. The technology for continuous infrared monitoring is available—the field is limited only by the imagination of the user.

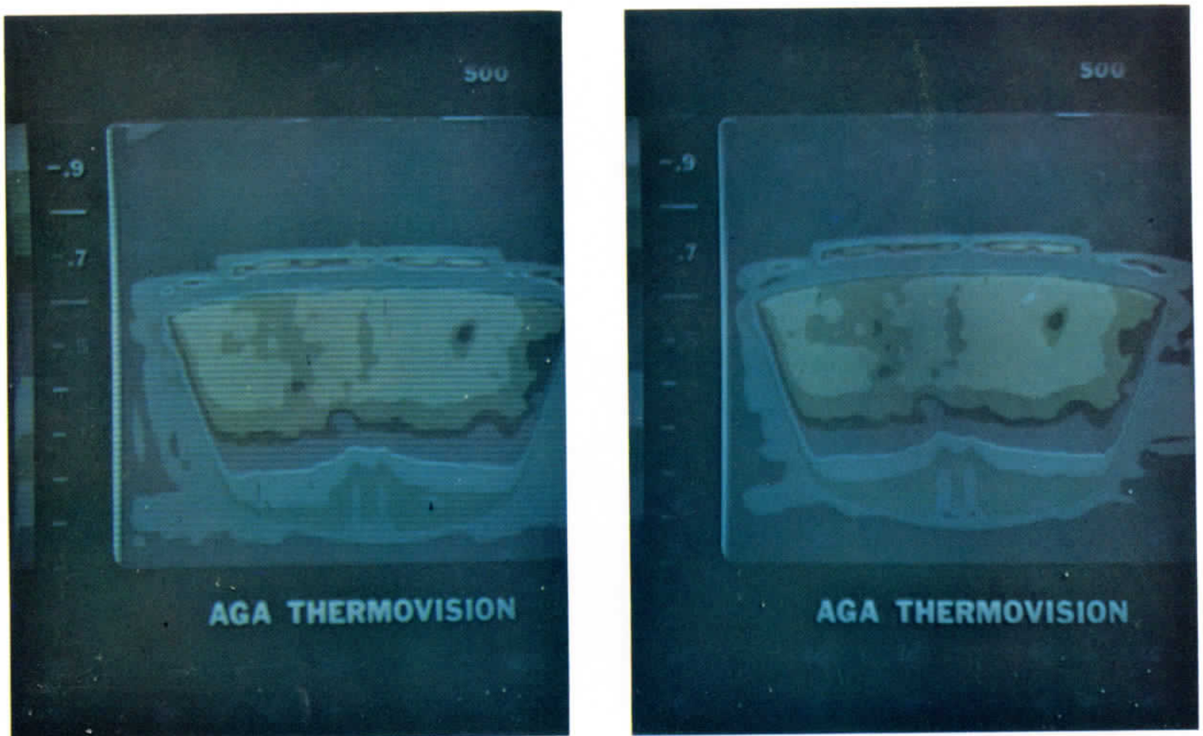


FIGURE 4 E A

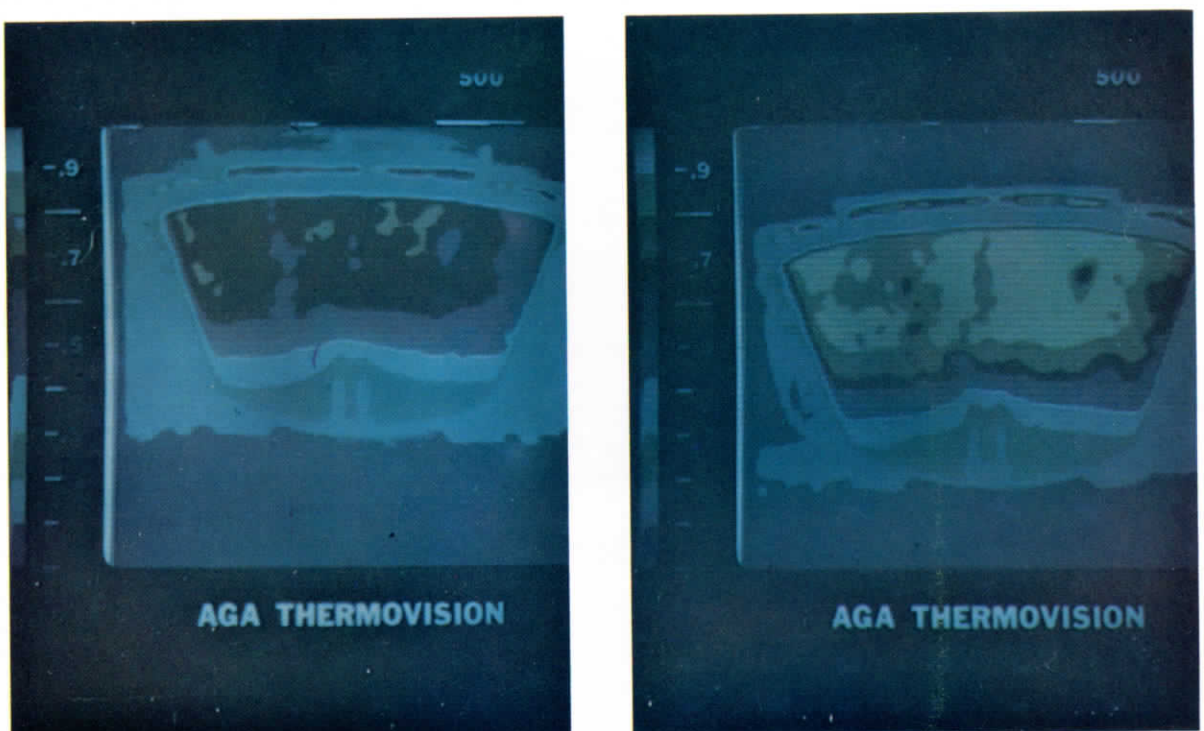


FIGURE 5 X2 H

THE USE OF THERMOGRAPHY ON SINTER STRANDS

Philip J. Watson
General Steels Division
British Steel Corporation, U.K.

One of the functions of the Research Organisation within B.S.C., is to provide a technical service and specialist knowledge on any aspect of steel production. This service is presently being provided in the area of Sinter Plant control, the aim being the improvement of overall plant efficiency and of sinter quality.

A small experiment using the AGA 750 camera was conducted in order to determine whether or not the burn through pattern could be seen on the surface of the bed, and, if so, could this information be used as a control parameter, as part of the overall scheme. The results obtained proved so successful it was realized that the regular thermographic surveys of this type would be very useful if undertaken just prior to a maintenance stop day, thus giving maintenance personnel prior knowledge of any areas requiring attention.

Sinter plants originated about the same time as large quantities of fine ore became available. This ore which cannot normally be used in a blast furnace because of its small particulate size adversely affecting permeability, can, by means of a sintering process, be altered in such a way, i.e. its particulate size increased, enabling it to be charged directly into a blast furnace.

This process involves mixing or blending the ore with coke, typically 4% and other additions in varying quantities. This mixture is then fed evenly onto a moving bed (known as a strand) where the surface layer is ignited as it passes under an array of coke oven gas burners. Here spontaneous ignition occurs because of the coke in the mix, and air being drawn down through the bed causes this flame front to propagate down through the material as it progresses along the strand. Figures 1a and 1b show a typical stand in operation.

In this particular case (there are exceptions) the ideal case is one in which burn-through, i.e. the point at which the flame front passes right through the bed; occurs evenly across the bed and a position a short distance before the end of the strand, thus ensuring that no unburnt materis is produced. The sinter is then screened and fine material, below 9mm, is fed back to the mixing process where it is recharged.

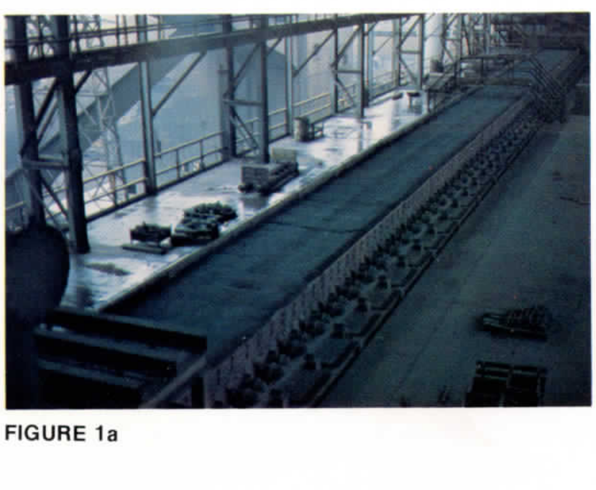


FIGURE 1a

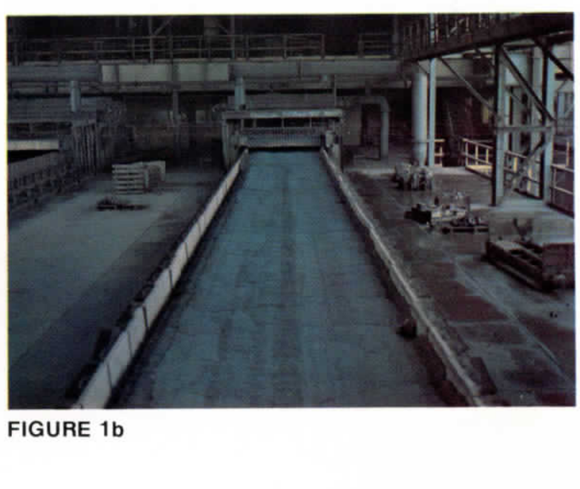


FIGURE 1b

THEORY

It follows from this explanation that the ideal isotherm pattern on the surface of a sinter strand would be as shown in Figure 2. Here the isotherms are represented by almost straight parallel lines indicating even burn through across the bed. In such a case, with the strands speed correctly adjusted so that final burn through occurred just before the end of the strand was reached, then:—

a) no unburnt sinter would leave the strand

b) there would be greater uniformity of sinter quality

c) the strands speed and hence throughput would be optimised.

METHOD AND RESULTS

Having decided what are desirable thermographic patterns, our 750 camera was used on plant to obtain some actual photographs. The camera was positioned on the bridge some 6 metres from the end of the reflecting shield and was looking up the strand towards the ignition hood, obtaining the view as seen in Figure 1b..

A distinct isotherm pattern did exist and by taking three or more consecutive but separate pictures, each with a different isotherm level, it is possible to build up a composite thermal picture and present this in a simplified graphic form. Figure 3a shows a general thermographic picture of the bed, the lighter shades being the hotter areas. In Figure 3b an isotherm representing a temperature of 145° C has been superimposed on the thermal picture. The graphic representation is shown in Figure 3c and as can be seen although there was a distinct pattern it did not conform to our ideal. Factors which could affect this pattern had to be considered, i.e. uneven ignition and spreader faults affecting permeability being the most suspect. No apparent spreader faults were visible and an even, unbroken bed of sinter was being produced with no irregularities. Although hidden faults could not be ruled out, it seemed more likely to be an ignition problem.

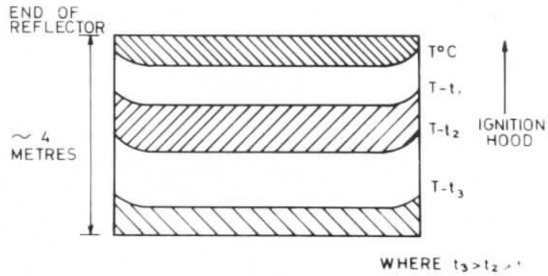


FIGURE 2 GRAPH SHOWING EXPECTED ISOTHERMS OF AN IDEAL SINTER STRAND

Shortly after this survey, all the burners in the ignition hood were replaced and some were found to be partially blocked with ammonium thiocyanate, a byproduct of the coke oven gas burned. A second survey was carried out shortly after this overhaul and the results clearly showed a great improvement, the thermographic pattern approaching that of the idealised thermogram. These results are shown in Figure 4a and graphic form in Figure 4b.

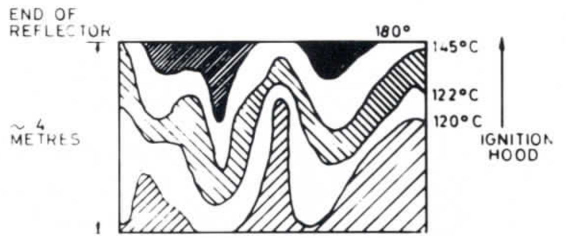


FIGURE 3c GRAPH SHOWNING ISOTHERMS ON THE SURFACE OF A SINTER STRAND

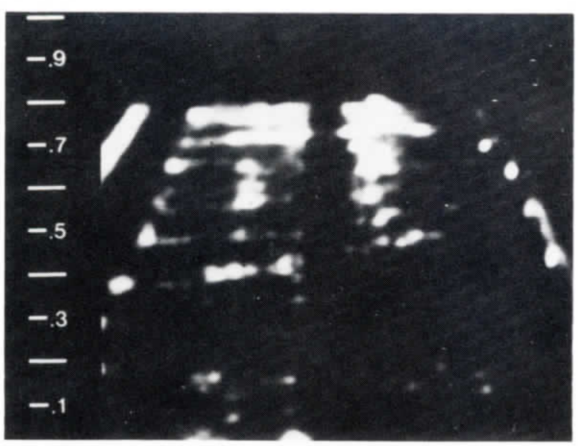


FIGURE 3a

FIGURE 3b

FIGURE 4a

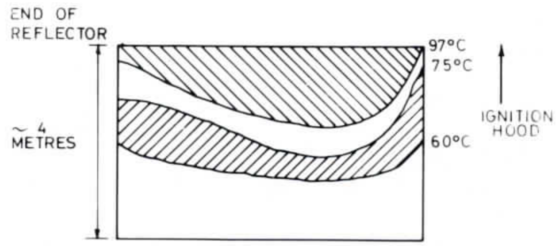
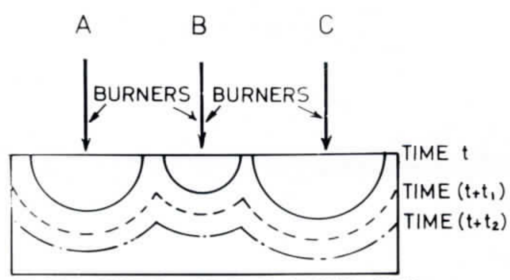


FIGURE 4b GRAPH SHOWING ISOTHERMS ON THE SURFACE OF A SINTER STRAND

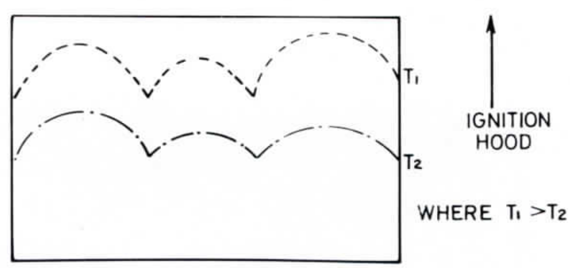
As a result of this overhaul the percentage of returned fines being produced was reduced considerably and theoretically the strand speed could have have increased, thus increasing throughput.

Although the results of the burner changes did show that it was the burners at fault, and that by looking at the thermographic pattern on the surface of a sinter bed it was possible to detect ignition faults, it did not explain why a particular pattern was obtained. One theory is that irregularities in the burners cause ignition to occur preferentially on certain parts of the bed. The preferential ignition pattern thus produced will remain on the surface of the sinter bed and can be recorded thermographically. This may become clearer by considering Figure 5a and the simple case of three burners, A, B and C, each operating with a different gas flow rate. This may be due to burner blockage, irregular burner design, burner position with respect to main gas supply line, etc. This varying gas flow rate results in different heat inputs from each burner and cause the area of bed under the burner with the greatest heat input burner 'C' to ignite first. Consequently its flame front moves down through the bed ahead of A and likewise A ahead of B. This flamefront profile is retained as it moves down through the bed. A thermographic scan of the bed's surface at this time would produce an isotherm as shown in Figure 5b. The areas where preferential ignition occurred, i.e. where the flame front is furthest from the bed's surface, show up as being coolest and the areas where ignition was last to occur show up as hotter lobes. This pattern progresses along the bed as the general temperature level of the isotherms fall. We can conclude from this that ignition faults and possibly spreader faults can be detected readily by studying the thermographic pattern on the surface of the sinter bed, and remedial action can be taken promptly.



CROSS SECTION OF THE SINTER BED SHOWING PROPOGATION OF FLAME FRONT

FIGURE 5a



ISOTHERM PATTERN PRODUCED ON THE SURFACE OF THE SINTER BED

FIGURE 5b

All of the previous results were obtained from a strand where the burners, aligned in rows, are all supplied with gas from one end of a common manifold. At a later date a different strand was surveyed and here the burners are aligned in rows and are supplied with gas from both ends, each end having a regulating valve. This particular strand's burners had all been changed fairly recently, no thermographic survey having been carried out previously. Pictures obtained showed up what appeared to be obvious ignition faults. Figures 6a and 6b indicate (according to our theory) preferential ignition occurring on the left hand side of the bed. This irregular ignition pattern was unlikely to be due to any of the recently fitted burners being blocked, and after explaining the meaning of the thermogram to a member of plant personnel, on his own initiative he made adjustments to gas flows on the ignition system in an attempt to correct the irregular pattern. Figures 7a and 7b taken 20 minutes later shows the effects of these adjustments. Preferential ignition is now occurring at either side of the centre and adjustments made to achieve this were limited to one side of the ignition system. It appears now with both side gas flows balanced, the pressure drop across the outer burners causes gas starvation to the inner burners indicating poor burner design and/or poor operating practice.

CONCLUSIONS

These two surveys clearly indicate that thermography can show up faults that are not readily, or in some cases impossible, to detect by other means. This can lead to more efficient operation of the plant and a clearer understanding of remedial action to be taken during the next maintenance stop. It is almost certain that other irregularities in the various parameters which affect sinter quality can be detected and work is continuing in this field.

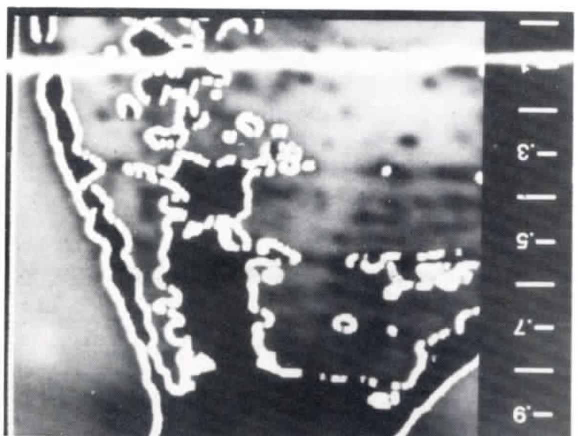


FIGURE 6a

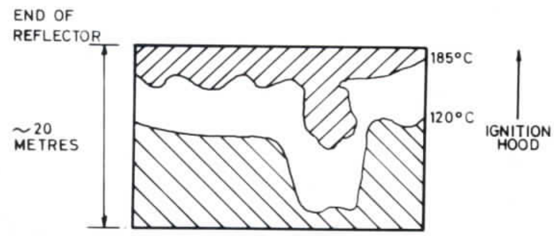


FIGURE 6b GRAPH SHOWING ISOTHERMS ON THE SURFACE OF A SINTER STRAND

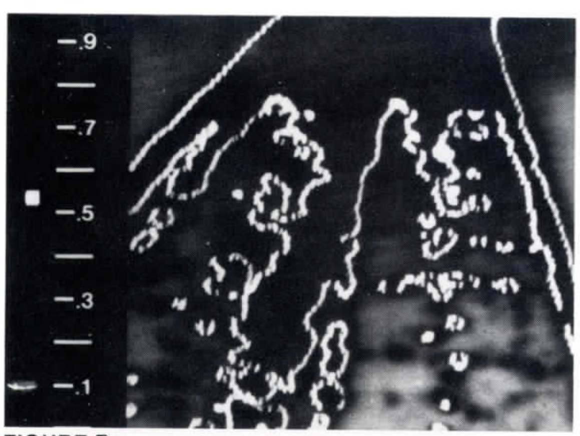


FIGURE 7a

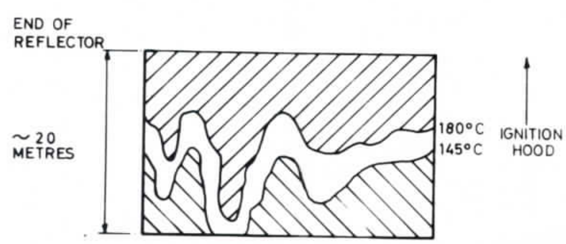


FIGURE 7b GRAPH SHOWING ISOTHERMS ON THE SURFACE OF A SINTER STRAND

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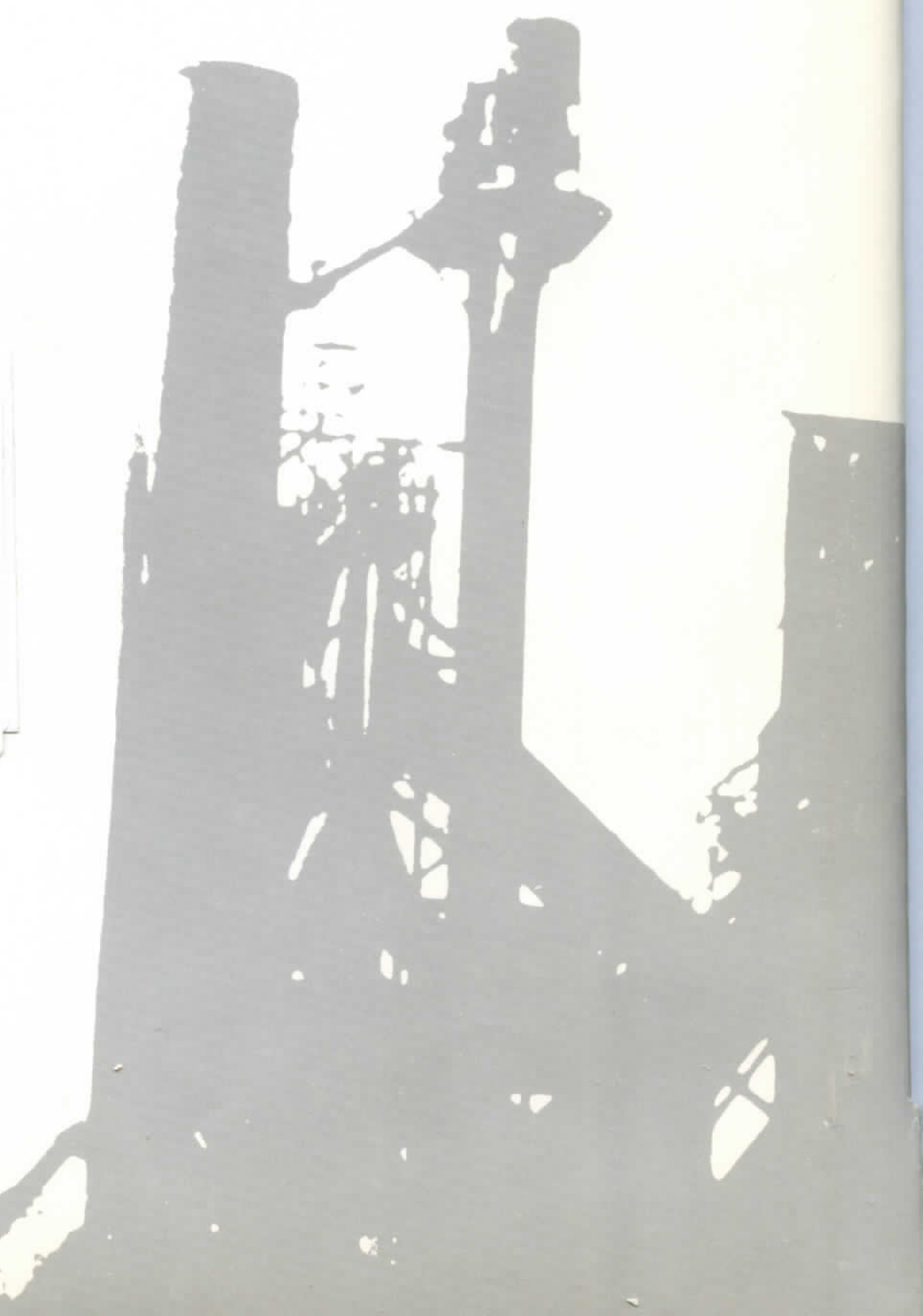
EKLUND INFRARED

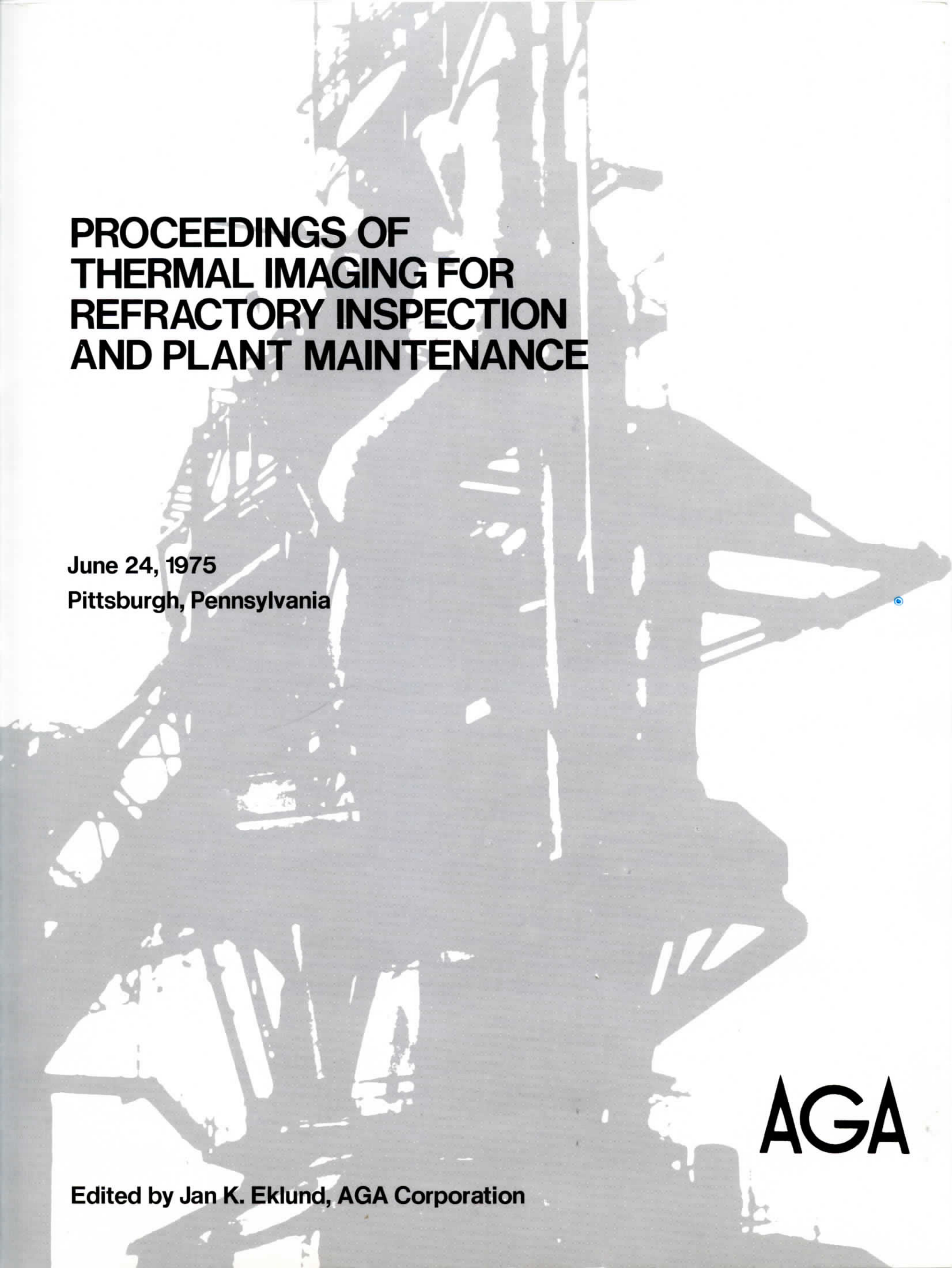
Eklund Innovation Inc.
SweSystem Airborne Gimbal Cameras
Jan K. Eklund
President
2985 Gordy Parkway
Marietta, GA 30066
Phone: 770-578-4435
Jan@eklundir.com
www.eklundir.com

St. Charles, Missouri 63301

AGA CORPORATION
1163 Chess Drive, Suite C
Foster City, California 94402

AGATRONICS LTD.
41 Horner Avenue
Toronto, Ontario M8Z 4X4





PROCEEDINGS OF THERMAL IMAGING FOR REFRACTORY INSPECTION AND PLANT MAINTENANCE

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