

TERMOGRAFIJA U KONTROLI OPREME U EKSPLOATACIJI THERMOGRAPHY IN THE INSPECTION OF IN-SERVICE EQUIPMENT

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Ključne reči

- infracrveno zračenje
- termogram
- reformer
- cevi

Izvod

U radu je analizirana primena termografije za kontrolu procesne opreme i cevovoda u eksploataciji. Karakteristični primeri ispitivanja opreme u procesnoj industriji su prikazani i objašnjeni.

UVOD

Objekti u našem okruženju razmenjuju toplotu neprekidnim apsorbovanjem i emitovanjem. Elektromagnetni spektar je manje više proizvoljno podeljen na izvestan broj traka, između kojih nema bitne razlike u zračenju. Sva zračenja podležu istim zakonima, a jedina razlika je u talasnim dužinama. U termografiji se koristi infracrveni deo spektra i on omogućava da se preko prikladnih uređaja ovaj deo pretvori u vidljiv signal, koji se zatim može interpretirati, /1/.

PRIMENA TERMOGRAFIJE

Termografija se zasniva na merenju intenziteta infracrvenog (IR) zračenja posmatranog objekta i na osnovu toga se određuje temperatura objekta. Relativni temperaturni odnosi određuju tačke hladno-toplo-vrelo.

Termografija se uspešno primenjuje u procesnoj industriji, rafinerijama, energetici, elektrotehnici, građevinarstvu, prevenciji požara, medicini, službi bezbednosti, vojnoj industriji, dakle gotovo neograničeno.

Pri izboru spektralnog opsega IR sistema najvažnija su sledeća tri kriterijuma:

1. Opseg temperatura ispitivanog objekta. Vinovim zakonom je pokazano da se talasna dužina kod koje se javlja maksimum zračenja smanjuje povišenjem temperature. Ovim zakonom se određuje maksimalna talasna dužina zračenja za gornju i donju temperaturu ispitivanog objekta, čime se dobija najpogodniji spektralni opseg.
2. Emisivnost. Emisivnost zavisi i od talasne dužine. Metal ima nisku moć emisije, ali obojeni metal obično ima visoku emisivnost, zavisno od boje. Sa povećanjem talasne dužine emisivnost opada pa je pogodniji IR uređaj koja radi u nižem spektralnog opsegu.

Keywords

- infrared radiation
- thermogram
- reformer
- tubes

Abstract

The application of thermography in the inspection of in-service processing equipment and pipelines is analysed. Typical examples of equipment inspection in the processing industry are presented and explained.

INTRODUCTION

Objects in our environment exchange heat by continuous absorption and emission. The electromagnetic spectrum is more or less randomly divided into a certain number of bands, with no substantial difference in radiation between them. All radiations obey the same laws, and the only difference is in wave lengths. The infrared part of the spectrum is used in thermography and is converted into a visible signal by convenient devices, which can then be interpreted, /1/.

THE APPLICATION OF THERMOGRAPHY

Thermography is based on the measurement of infrared (IR) radiation intensity of the considered object, and accordingly, the object temperature is determined. Relative temperature correlations determine cold-warm-hot spots.

Thermography has been successfully applied in process industry, oil refineries, energetics, electrotechnics, civil engineering, fire prevention, medicine, safety services, arms industry, and practically without limits.

In the selection of the IR spectrum range, the following three criteria are most important:

1. Temperature range of the tested object. Vin's law has shown that wave length at which maximal radiation occurs decreases with temperature increase. According to this law maximal radiation wave lengths for upper and lower temperatures are determined for the tested object, thus estimating the most convenient spectral range.
2. Emissivity. Emissivity depends on wave length. Metals have low emissivity, but painted metal surfaces can have high emissivity, depending on colour. With increase in wave length the emissivity decreases, so IR devices operating in the lower spectral range are more convenient.

3. Uticaj atmosfere. Atmosferski sastojci apsorbiraju, propuštaju, reflektuju, rasipaju i emituju termičko IR zračenje. Uticaj atmosfere zavisi od rastojanja objekta i IR opreme i od meteoroloških uslova. Pri udaljenosti do 50 mm, a maloj relativnoj vlažnosti vazduha, uticaj atmosfere u industrijskim merenjima je zanemarljiv. Voda je dobar apsorber i dobar radijator IR zračenja. Uticaj isparenja vode se rešava upotrebom pogodnih filtera.

Na podešenom ekranu starijih termografskih uređaja svetla mesta na termogramu označavaju zone povišene temperature na ispitivanom objektu. Tamnija mesta označavaju zone nižih temperatura (sl. 1-2). Moguće je i drugačije podešavanje uređaja tako da slika na termogramu bude suprotna. Novije generacije termografskih uređaja rade na istom principu, ali su zbog slike u bojama na monitoru izabrane izoterme posle obrade na kompjuteru jasno izražene (sl. 3-6).

Zone povišenih i sniženih temperatura („tople“ i „hladne“ tačke) nastale zbog oštećene i neravnomerne termoizolacije se tačno i pouzdano utvrđuju termografskim ispitivanjem. Topla mesta se na snimku javljaju kao svetle zone na opremi kada je radni fluid topliji od okoline, a kao tamne zone kada je on hladniji.

Preporučuje se termografsko ispitivanje pri najvišem termičkom opterećenju, pri najvećoj razlici temperatura radnog fluida i okoline, kada je razmena toplote sa okolinom intenzivna, /1-2/.

Materijal spoljne oplata izolacije može ometati ispitivanje opreme u radu. Oplata je obično od aluminijumskog lima niske emisivnosti i visoke reflektivnosti, što daje lažne indikacije refleksijom okolnih tela. Snimanjem objekata iz različitih pozicija, uz zaklanjanje izvora refleksije postiže se veća pouzdanost dobijenih rezultata, /3-4/.

TERMOGRAFSKO ISPITIVANJE REFORMERA I DRUGE OPREME U PROIZVODNJI AMONIJAKA

Sekcija reforminga je vitalni deo pogona za proizvodnju amonijaka. Procesi unutar primarnog reformera se odvijaju u izuzetno teškim uslovima, zbog čega se njegov rad prati odgovarajućim ispitivanjem bez razaranja. Unutrašnjost reformera se osmatra sa platformi, kroz otvore na ozidu peći, bez direktnog kontakta sa atmosferom peći. Otvori su raspoređeni na raznim kotama reformera da bi sve cevi mogle da se kontrolišu, /5-6/.

Ovakvo ispitivanje reformera omogućava:

1. Optimizaciju procesa sagorevanja u odnosu na različita opterećenja reformera.
2. Detekciju vrelih tačaka ili zona na cevima primarnog, odnosno na glavi i telu sekundarnog reformera.
3. Kontrolu temperature merene termoparovima ili optičkim pirometrom.

Korišćena aparatura „Petroscanner“ /2/ meri temperature do 1500°C. Sastoji se od sledećih komponenata:

1. Kamere za registrovanje infracrvenog zračenja sa ugrađenim plamenim filterom.
2. Monitora sa ugrađenim plamenim filterom, na kome se prikazuje vizuelno registrovano zračenje.
3. Ostale opreme potrebne za rad aparata (teleobjektiv, sonde, izvor napajanja).

3. Effect of the atmosphere. Atmospheric constituents absorb, transmit, reflect, dissipate and emit thermal IR radiation. The atmospheric effect depends on the object to IR equipment distance and environmental conditions. At distances less than 50 mm and low air humidity, atmospheric effects in industrial measurements are negligible. Water is a good absorber and emitter of IR radiation. The effect of water evaporation is solved using convenient filters.

On the adjusted monitor of older thermographic devices light areas on the thermogram indicate zones of elevated temperature on the tested object. Darker areas indicate zones of lower temperature (Figs. 1-2). Various adjustments of the device are possible, with a negative image on the thermogram. Newer generations of devices operate on the same principle, and due to coloured images on the monitor, the selected isotherms are clearly indicated after elaboration on the computer (Figs. 3-6).

Zones of increased and decreased temperatures (“hot” and “cold” spots) caused by damaged and non-uniform thermal insulation are detected accurately and reliably by thermographic tests. Hot spots in the image appear as bright zones on the equipment when the operating fluid is warmer than the environment, and as dark zones when it is cooler.

Thermographic testing is recommended at highest thermal loading, at the largest temperature difference between operating fluid and environment, when heat exchange with the environment is intense, /1-2/.

Outer insulation covering can obstruct in-service testing of the equipment. The covering is an aluminium foil of low emissivity and high reflexivity, which produces false indications from reflections of neighbouring objects. Recording objects from different positions and covering the sources of reflections may give results of higher reliability, /3-4/.

THERMOGRAPHIC INSPECTION OF REFORMERS AND OTHER EQUIPMENT IN AMMONIA PRODUCTION

The reforming section is the vital part of equipment for ammonia production. Processes in the primary reformer take place in extremely difficult conditions, wherefore these operations are monitored by corresponding non-destructive tests. The reformer interior is monitored from platforms, through openings in the furnace wall, without direct contact with furnace atmosphere. Openings are distributed at different reformer levels for the monitoring of all tubes, /5-6/.

This type of reformer testing enables:

1. Optimization of the combustion process in relation to different loads of reformer.
2. Detection of hot spots or zones on tubes of the primary, or on the head and body of the secondary reformer.
3. The control of temperature measured by thermocouples or by pyrometer.

The applied “Petroscanner” /2/ measures temperatures up to 1500°C. It consists of following components:

1. Cameras for recording infrared radiation, with built-in flame filter.
2. Monitoring screen for visualization of recorded radiation with built-in flame filter.
3. Other equipment necessary for device operation (tele-objective, probes, power source).

Utvrđivanje termičkih mapa

Utvrđivanje termičke mape unutrašnjosti reformera omogućava dobijanje potrebnih informacija za optimizaciju toplotnog režima. Termičke mape daju raspodelu temperature za različita opterećenja cevi u blizini plamena i udaljenih delova pri startu pogona ili pred izvođenje remontnih radova i po završetku istih. Termičke mape treba obavezno uraditi pri startovanju novog postrojenja, jer su od značaja za poređenje raspodele temperatura posle određenog broja sati rada sa početnim stanjem u unutrašnjosti reformera.

Utvrđivanje prisustva koksa na unutrašnjoj strani cevi

Uvođenjem vodene pare se omogućava osnovna hemijska reakcija u reformeru, ali se u isto vreme sprečava pojava čađi (koksa) na unutrašnjoj strani cevi. Ako se koks nataloži, razmena toplote između fluida unutar cevi i zida cevi će biti ograničena. Temperatura zida cevi u tom slučaju lokalno može da poraste do nivoa kada mehaničke karakteristike materijala cevi više ne zadovoljavaju radne uslove. Porast temperature cevi je proporcionalan debljini naslage koksa. Termografsko ispitivanje omogućava brzo utvrđivanje prisustva koksa kao i efikasno praćenje operacije njegovog uklanjanja pomoću vodene pare, /4/.

Kontrola temperatura dobijenih merenjem termoparovima i optičkim pirometrom

Zbog ograničene mogućnosti za postavljanje termoparova na svakoj cevi i celom njenom dužinom, termografska metoda pruža veće pogodnosti za kontrolu rada peći.

Glavnu teškoću pri merenju temperature cevi unutar reformera pirometrima predstavlja to što su cevi reformera i sam pirometar razdvojeni plamenom i atmosferom raznih gasova. Prisutni gasovi apsorbuju veliki deo energije emitovane od strane cevi pa temperatura koju registruje optički pirometar neće biti proporcionalna temperaturi cevi. Da bi se izbegla ova nepogodnost, „Petroscanner“ /2/ u svojoj kameri za infracrveno snimanje ima ugrađen filter koji ne propušta zračenja talasnih dužina manjih od 3,6 μm i većih od 4,1 μm . Ovaj interval je odabran prema apsorpcionom spektru gasa u kome postoji samo jedan „prozor“ koji propušta parcijalno apsorbovanu energiju od strane cevi.

Međutim, može se desiti da su temperature izmerene termografski više od temperatura izmerenih termoparovima i za desetinu stepeni. Krajevi termopara su zavareni za cev pa se meri i temperatura naslaga na unutrašnjoj površini cevi, koje uvek imaju višu temperaturu od površine cevi.

Radi zaštite sočiva kamere od indirektnog dejstva plamena koristi se azbestni toplotni štitnik na kome se nalazi kružni otvor pokriven laminatom kvarca. Kvarc je transparentan za infracrveno zračenje talasnih dužina manjih od 4,5 μm i služi kao dodatni filter za zračenja viših talasnih dužina. Zbog toga je pouzdanije merenje temperatura pomoću „Petroscanner“ nego pomoću optičkog pirometra.

Sa stanovišta sprovođenja termografskog ispitivanja poželjno bi bilo izvršiti antikorozijsku zaštitu spoljne strane oplata, premazom visoke emisivnosti.

Na sl. 1. su prikazani i ukratko objašnjeni rezultati ispitivanja reformera, koji su omogućili optimizaciju procesa /3/.

Na sl. 2. su prikazani termogrami ispitivanja sfernog rezervoara i posude pod pritiskom, /3/.

Determination of thermic maps

Determination of thermic maps of the reformer interior enables obtaining necessary information for thermal regime optimization. Thermic maps show temperature distribution for different loads on tubes in the flame vicinity and remote parts at process start-off or prior to reparation, and after its completion. Thermic maps are obligatory when starting off new equipment because of their significance for comparing temperature distribution in the reformer interior after a pre-determined number of working hours in the initial state.

Determination of coke presence on tube inner side

Introducing steam enables basic chemical reaction in the reformer, and at the same time prevents occurrence of soot (coke) on the tube inner side. If coke deposits, the heat exchange between fluid and inner tube wall will be limited. Tube wall temperature in this case can locally increase to the level at which mechanical properties of tube material do not satisfy operating conditions. The increase of tube temperature is proportional to coke deposit thickness. Thermographic testing enables fast determination of coke presence as well as efficient monitoring of its removal by steam, /4/.

Temperature inspections obtained by thermocouple- and optical pyrometer measurements

Due to limited possibility for thermocouple positioning on each tube and along its length, the thermographic method is more suitable for furnace operation monitoring.

Major difficulty of measuring tube temperature inside the reformer by pyrometer is in that the reformer tubes and pyrometer itself are separated by flame and various gases. These gases absorb significant part of the energy emitted by the tubes, so the temperature registered by optical pyrometer will not be proportional to tube temperature. In order to avoid this inconvenience, „Petroscanner“ /2/ has a built-in filter in its camera for infrared screening which does not transmit radiation wave lengths less than 3.6 μm and higher than 4.1 μm . This interval is selected according to the absorption spectrum of the gas having a single „aperture“ which transmits partially absorbed energy by the tube.

Anyhow, temperatures measured by thermography might be higher than those measured by thermocouples even up to ten degrees. Thermocouple ends are welded to the tube and so they measure the deposit temperatures on inner tube wall, which are always higher than on the tube surface.

In order to protect the camera lens from indirect flame effects, an asbestos heat screen is used with a round opening covered by quartz laminate. Quartz is transparent for infrared radiation of wave lengths smaller than 4.5 μm and serves as an additional filter for radiation of higher wave lengths. This is why „Petroscanner“ temperature measurements are more reliable than by optical pyrometers.

From a thermographic testing point of view, it is desirable to perform anti-corrosive protection of the outer covering with high emissivity coating.

Results of reformer tests, that have enabled process optimization, are presented and shortly explained in Fig. 1, /3/.

Figure 2 presents thermograms obtained from spherical storage tank- and pressure vessel tests, /3/.



a. Ravnomerna raspodela temperature na južnom zidu sekundarnog reformera
a. Uniform temperature distribution on south wall of secondary reformer.



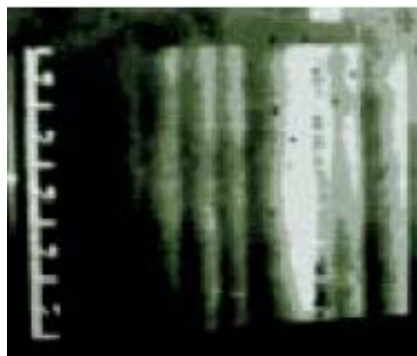
b. Toplo mesto na horizontalnom delu i kolenu transfer linije
b. Hot spot on horizontal segment and on knee of transfer line.



c. Detaljna raspodele temperature transfer linije sa slike b
c. Detailed temperature distribution on transfer line from figure b.



d. Povišena temperatura na tri reformerske cevi
d. Elevated temperature of three reformer tubes.

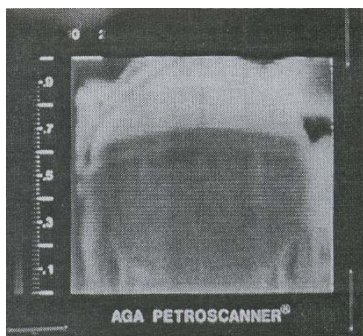


e. Snimak iz drugog ugla tri reformerske cevi
e. Image from another angle of three reformer tubes.

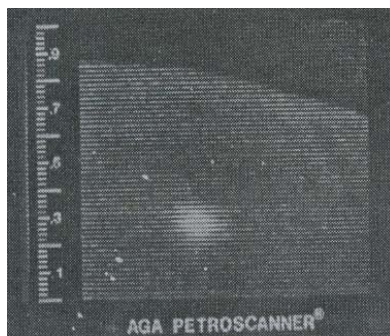


f. Povišena temperature cevi pre produvanja pare
f. Increased tube temperature before steam blowing.

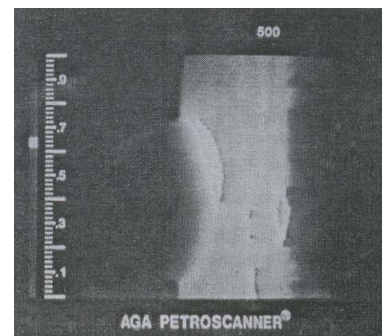
Slika 1. Karakteristični termogrami dobijeni pri ispitivanju reformera
Figure 1. Typical thermograms obtained by testing of the reformer.



a. Određivanje nivoa u sfernom rezervoaru na osnovu različitih temperatura tečnosti i gasa
a. Determining the level in spherical storage tank based on different temperature of liquid and gas.



b. Zagrevanjem ispitivanog područja na sfernom rezervoaru određeno je mesto oštećene izolacije
b. Heating the tested region on spherical storage tank determines damaged insulation location.



c. Vruće tačke na mestu priključka na plaštu posude
c. Hot spots at location of connection to the vessel mantle.

Slika 2. Karakteristični termogrami dobijeni pri različitim zahtevima pri ispitivanju opreme u procesnoj industriji
Figure 2. Typical thermograms obtained for different requirements in the tests of industrial processing equipment.

Karakteristika ovih ispitivanja su samo kvalitativne indikacije, jer dobijene crno bele slike ne dopuštaju precizniju ocenu. Zbog toga je važna saradnja između pogonskog osoblja i službe kontrole prilikom obavljanja termografskog ispitivanja radi pravilne interpretacije dobijenih rezultata. Radi efikasnije termografske kontrole na nekim delovima reformera izvršene su manje izmene u konstrukciji postavljanjem novih otvora za posmatranje i dodatnih platformi u cilju boljeg pristupa.

Only qualitative indications are typical for these tests, since the obtained black and white images do not allow for more accurate assessment. Thus, cooperation between operations and inspection personnel is essential during thermographic tests for correct interpretation of obtained results. A more efficient thermographic test required slight changes in the design of some reformer parts, introducing new openings for monitoring and additional platforms for better access.

Treba pomenuti da pored kontrole odvijanja procesa unutar reformera, termografska kontrola se primenjuje u inspekciji spoljnih delova reformera radi utvrđivanja stanja vatrostalnog ozida u cilju sprečavanja energetskih gubitaka.

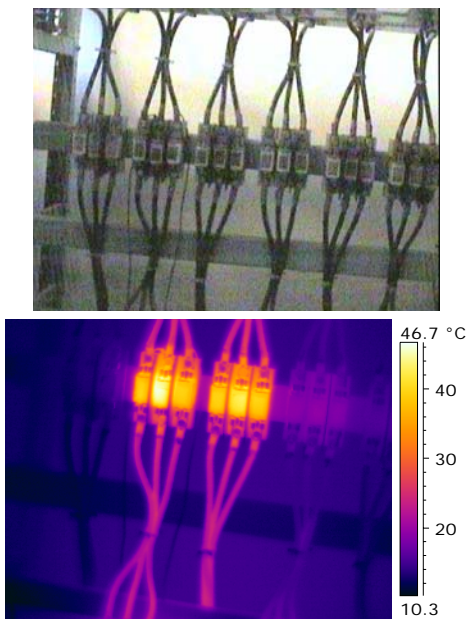
TERMOGRAFSKO ISPITIVANJE U BOJAMA

Zahvaljujući spektru boja termografskim ispitivanjem se na snimku može dobiti vrlo precizna raspodela temperatura na objektu (sl. 3-6) /4/. Ova su ispitivanja izvedena na otvorenom prostoru, pa su uslovi ispitivanja važni za kvalitet dobijenih snimaka. Spoljna temperatura je bila 5°C, vetar slab, 1–2 m/s, pretežno oblačno. Ispitivanje izvedeno posle zalaska sunca. Korišćena je infracrvena kamera „Flir P60“ sa fabričkim objektivom –24°.

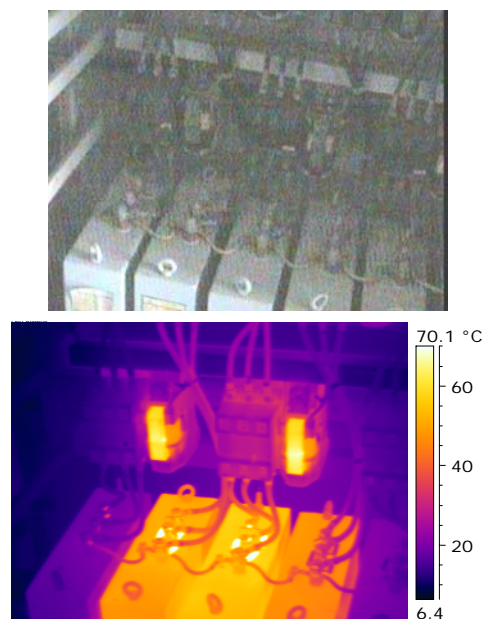
It is to mention that, in addition to monitoring processes inside the reformer, thermographic tests are used for the inspection of outer reformer parts in assessing the state of heat resistant walls in order to prevent energy loss.

THERMOGRAHPIC TESTING IN COLOUR

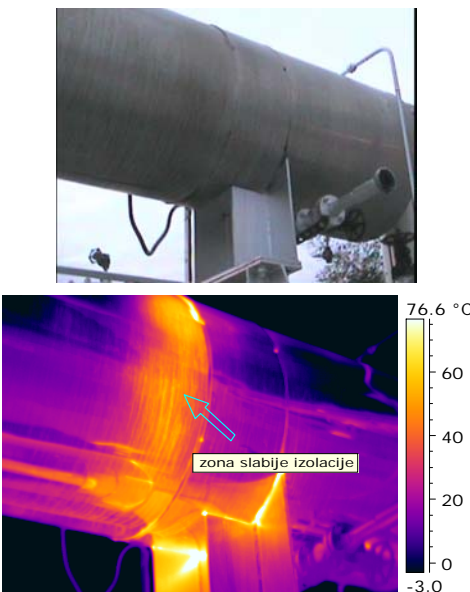
Thanks to the colour spectrum, thermographic tests may produce images with very precise temperature distributions on the object (Figs. 3-6) /4/. Such tests had been performed outdoors, and so the testing conditions are of high significance for obtained image quality. Outer temperature was 5°C, slow breeze, 1–2 m/s, mostly cloudy. Testing was performed after sunset. “Flir P60” infrared camera was used, with the industrial objective –24°.



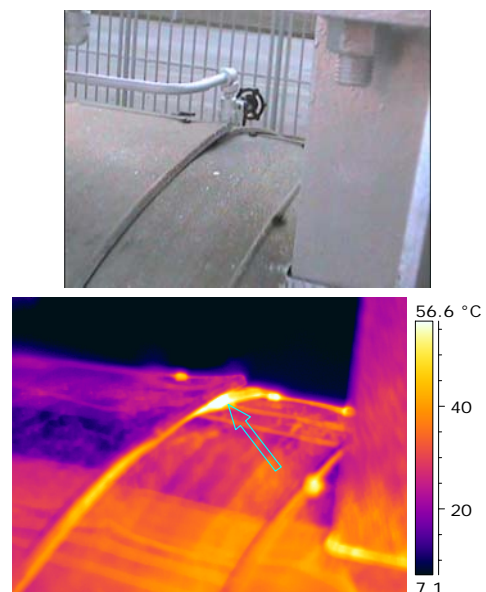
Slika 3. Izgled i termografski snimak električnih priključaka
Figure 3. View and thermographic image of electrical connections.



Slika 4. Izgled i termografski snimak kondenzatora
Figure 4. View and thermographic image of condensers.



Slika 5. Izgled posude i termografski snimak izolacije
Figure 5. View of vessel and thermographic image of insulation.



Slika 6. Odavanje toplote na spoju segmenta posude: izgled i termografski snimak
Figure 6. Heat emission at the vessel joint segment: view and thermographic image.

Nalaz: Na ispitivanoj opremi nisu nađena značajna odstupanja temperaturnih polja. Raspodela temperature na uključenim priključcima je ravnomerna (sl. 3). Krajnji levi kondenzator je bio uključen, a termografski snimak pokazuje da je on hladan (sl. 4), što ukazuje na mogućnost njegovog oštećenja. Na sl. 5. je vidljiva zona lošije izolacije na posudi. Prekomerno odavanje toplote je otkriveno na posudi, sl. 6.

ZAKLJUČCI

Opisano termografsko ispitivanje reformera uređajem starije generacije je pokazalo da se ova tehnika ispitivanja bez razaranja može veoma uspešno koristiti za vođenje procesa tokom rada opreme.

Termografskim ispitivanjem kamerom najnovije generacije pouzdanost ocene opšteg stanja proizvodnog pogona je značajno povećana, što je potvrđeno kako ispitivanjem elektroinstalacije tako i ispitivanjem izolacije na procesnoj opremi.

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Findings: No significant deviations in the temperature field were discovered on the tested equipment. Temperature distribution on operating connectors is uniform (Fig. 3). Final left condenser was in operation, but the thermographic image shows that it is cold (Fig. 4), indicating the possibility of its damage. In Fig. 5 a zone of bad insulation on the vessel is visible. Redundant heat emission is detected on the vessel, Fig. 6.

CONCLUSIONS

Described thermographic testing of the reformer by old generation equipment showed that this non-destructive testing technique can be used very successfully for process control during operation of industrial equipment.

Thermographic tests with camera of newest generation enhances the reliability of state assessment of operating equipment in general, and is confirmed by tests of electrical installations and also by tests of insulations on processing equipment.