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REPLACING IONIZATION-BASED FLAME RECTIFICATION WITH INFRARED FLAME SUPERVISION IN GAS-FIRED CONVEYOR OVENS: AN ENGINEERING CASE STUDY

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RESUMO: Sistemas de Ignição Direta por Centelha (DSI) com sensoriamento de chama por retificação/ionização são amplamente utilizados em equipamentos comerciais de cocção a gás, devido ao seu baixo custo e simplicidade mecânica. Contudo, o sensoriamento por retificação de chama depende intrinsecamente da posição física de um eletrodo sensor dentro do envelope da chama, o que o torna vulnerável a desligamentos indevidos quando há flutuação na pressão de fornecimento de gás, situação comum em instalações comerciais a gás natural durante períodos de pico de demanda. Este artigo apresenta um estudo de caso de engenharia sobre a reformulação de um sistema de segurança de queimador implementada em uma frota de fornos comerciais de esteira a gás, na qual a retificação de chama por ionização foi substituída por supervisão óptica de chama por infravermelho (IV). A arquitetura reformulada dissocia a confirmação de chama do posicionamento preciso do eletrodo, exigindo apenas que a chama permaneça dentro do campo de visão de um sensor infravermelho fixo. É relatada a implementação em campo em onze unidades convertidas, em seis instalações de clientes distintas, acompanhada de dados operacionais que indicam redução acentuada de desligamentos indevidos, redução de devoluções de equipamento e eliminação da necessidade recorrente de deslocamento de técnico para reajuste da pressão de gás em campo. O estudo de caso tem por objetivo documentar uma abordagem de engenharia replicável para melhorar a robustez de sistemas de segurança de queimadores em equipamentos comerciais a gás sujeitos a condições variáveis de pressão de fornecimento.

Palavras-chave: supervisão de chama. detecção de chama por infravermelho. ignição direta por centelha. controle de segurança de queimador. fornos comerciais a gás. retificação de chama.

ABSTRACT: Direct Spark Ignition (DSI) systems using flame-rectification (ionization) sensing are widely deployed in commercial gas-fired cooking equipment due to their low cost and mechanical simplicity. However, flame-rectification sensing is intrinsically dependent on the physical position of a sensing electrode within the flame envelope, which makes it vulnerable to nuisance shutdowns when gas supply pressure fluctuates, as is common in commercial natural-gas installations during peak-demand periods. This paper presents an engineering case study of a burner safety-system redesign implemented across a fleet of commercial gas-fired conveyor ovens, in which ionization-based flame rectification was replaced with infrared (IR) optical flame supervision. The redesigned architecture decouples flame confirmation from precise electrode placement, instead requiring only that the flame remain within the field of view of a fixed-position IR sensor. Field deployment across eleven converted units at six customer sites is reported, along with operational data indicating a marked reduction in nuisance lockouts, a reduction in equipment returns, and the elimination of recurring on-site technician dispatches previously required for gas-pressure re-regulation. The case study is intended to document a replicable engineering approach for improving burner safety-system robustness in commercial gas appliances subject to variable supply-pressure conditions.

Keywords: flame supervision. infrared flame detection. direct spark ignition. burner safety control. commercial gas ovens. flame rectification.

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RESUMEN: Los sistemas de Encendido Directo por Chispa (DSI, por sus siglas en inglés) con detección de llama por rectificación/ionización se utilizan ampliamente en equipos comerciales de cocción a gas debido a su bajo costo y simplicidad mecánica. Sin embargo, la detección por rectificación de llama depende intrínsecamente de la posición física de un electrodo sensor dentro de la envolvente de la llama, lo que la hace vulnerable a apagados indebidos cuando fluctúa la presión de suministro de gas, situación común en instalaciones comerciales de gas natural durante períodos de alta demanda. Este artículo presenta un estudio de caso de ingeniería sobre el rediseño de un sistema de seguridad de quemador implementado en una flota de hornos comerciales de banda transportadora a gas, en el cual la rectificación de llama por ionización fue reemplazada por supervisión óptica de llama por infrarrojo (IR). La arquitectura rediseñada desacopla la confirmación de llama del posicionamiento preciso del electrodo, requiriendo únicamente que la llama permanezca dentro del campo de visión de un sensor infrarrojo fijo. Se reporta la implementación en campo en once unidades convertidas, en seis instalaciones de clientes distintas, junto con datos operativos que indican una reducción marcada de apagados indebidos, una reducción de devoluciones de equipos y la eliminación de la necesidad recurrente de desplazamiento de técnicos para reajuste de presión de gas en campo. El estudio de caso tiene como objetivo documentar un enfoque de ingeniería replicable para mejorar la robustez de los sistemas de seguridad de quemadores en equipos comerciales a gas sujetos a condiciones variables de presión de suministro.

Palabras clave: supervisión de llama. detección de llama por infrarrojo. encendido directo por chispa. control de seguridad de quemador. hornos comerciales a gas. rectificación de llama.

1 INTRODUCTION

Commercial gas-fired cooking equipment, including conveyor ovens used in high-throughput foodservice operations, relies on burner safety-control systems to confirm the presence of a stable flame before allowing continued flow of fuel gas. The most common architecture found in this equipment class is Direct Spark Ignition (DSI) combined with flame-rectification sensing, in which an ignition-control module generates a spark to ignite the burner and subsequently monitors a microampere-level ionization current flowing between a sensing electrode and the grounded burner body through the ionized flame gases [1], [2]. Loss of this current is interpreted by the control module as loss of flame, triggering immediate closure of the gas valve as a safety response.

While flame rectification is a mature and widely adopted technology, its performance is dependent on the sensing electrode maintaining a consistent physical position relative to the flame body [3], [4]. This dependency becomes an operational liability in field installations where gas supply pressure is not perfectly stable, a condition frequently observed in commercial and light-industrial settings during periods of peak network demand or inconsistent utility supply [5], [6]. Under such conditions, flame shape and position shift, and the sensing electrode can lose reliable contact with the ionized region even though combustion is proceeding normally, resulting in a nuisance shutdown.

This paper documents an engineering redesign undertaken to address this failure mode in a fleet of commercial gas-fired conveyor ovens, replacing the ionization-based sensing element with an infrared (IR) optical flame scanner while retaining the existing spark-ignition and digital burner-control architecture. The remainder of this paper is organized as follows: Section 2 reviews the physical principles and known limitations of flame-rectification sensing and the alternative optical flame-detection technologies; Section 3 characterizes the natural-gas supply-pressure variability that motivated this work; Section 4 states the problem observed in the field; Section 5 describes the redesigned system architecture; Section 6 reports the field implementation; Section 7 presents operational results, including a summary cost-impact table; Section 8 discusses the findings and their generalizability; and Section 9 concludes the paper.

2 BACKGROUND AND PRIOR ART

2.1 Flame-rectification (ionization) sensing

Flame-rectification sensing exploits the fact that combustion produces a partially ionized gas region capable of conducting a small, asymmetric current when a voltage is applied between a sensing electrode and a grounded reference, typically the burner itself. This asymmetry, arising from the differing electron and ion mobilities in the flame plasma, allows a control module to distinguish a genuine flame from its absence [1], [7]. The method is inexpensive and mechanically simple, which accounts for its broad adoption in commercial and residential gas appliances [2].

A substantial body of combustion-engineering literature has characterized the sensitivity of ion-current-based flame sensing to electrode geometry and placement. Xu et al. [4] conducted a controlled parametric study of an ion-current flame sensor and reported that the measured ion current is strongly sensitive to the radial and vertical position of the sensing electrode relative to the flame front, growing approximately linearly with excitation voltage but varying substantially with electrode placement; the authors explicitly identify weak and position-dependent ion current as "the critical defect" limiting the reliability of this sensing principle. Ding et al. [3] similarly report that flame-ionization current in premixed heating-appliance burners is sensitive to combustion-state variation, and propose combining ionization current with chemiluminescence signals to improve monitoring robustness. More broadly, Docquier and Candel [7], in a widely cited review of combustion control and sensing technologies, note that ionization-based sensing methods are attractive for their simplicity but are comparatively more susceptible to signal degradation from geometric and environmental variation than optical sensing approaches.

2.2 Optical (infrared and ultraviolet) flame detection

An alternative, longer-established approach to flame supervision relies on optical detection of radiation emitted by the flame itself, in either the infrared (IR) or ultraviolet (UV) spectral bands [8], [9]. Optical flame scanners of this type are well established in industrial burner-management systems, particularly in boiler and process-heater applications, where they are valued for their tolerance to flame movement and their compatibility with burners operating across a wider range of firing conditions [9], [10]. IR detectors respond to infrared radiation emitted by hot combustion products and are generally well suited to hydrocarbon flames with strong infrared emission, while UV detectors respond to ultraviolet radiation characteristic of the combustion reaction zone itself and are highly responsive but more susceptible to false triggering from unrelated UV sources such as arc welding [8], [10]. Combined UV/IR detectors, which require simultaneous confirmation from both spectral bands, are used in high-reliability industrial applications specifically to reduce false-alarm rates [10].

Optical detection has historically been associated with higher unit cost than flame rectification and has therefore been less common in smaller commercial cooking equipment, where flame rectification has remained the incumbent technology despite its known sensitivity to flame-position variation. NFPA 85 explicitly mandates self-checking capability for continuously operating UV flame scanners on larger combustion systems, reflecting industry recognition of the reliability considerations associated with optical detection technology in continuous-duty service [11].

2.3 Prior art in flame supervision and pressure-related burner control

The general principle of flame-rectification sensing and its electrical basis is treated comprehensively in the classical monograph by Lawton and Weinberg [1], which remains a standard reference on the electrical properties of flames, including ionization behavior relevant to flame-sensing applications. Related early work by Hardesty and Weinberg [12] on electrical control of particulate emissions from flames further documents the electrical character of the combustion zone exploited by ionization-based sensing. Sanz et al. [13] examined advanced monitoring of industrial burners based on fluctuating flame signals, underscoring that flame-generated electrical and optical signals are both subject to combustion-state fluctuation, motivating the use of more geometrically tolerant sensing principles in variable operating conditions.

The engineering contribution reported in the present paper is not the invention of infrared flame sensing as a general technology, which is well established in industrial burner-management practice [9], [10], but rather its targeted integration into the ignition and burner-control architecture of a specific class of commercial gas-fired conveyor ovens, as a direct engineering response to a documented field-reliability problem associated with gas supply-pressure variability.

3 GAS SUPPLY-PRESSURE VARIABILITY AS AN OPERATING CONDITION

Natural-gas local distribution companies (LDCs) are required to plan for reliable service across substantial swings in short-term demand, which can occur on a daily or even hourly basis, particularly during periods of high aggregate consumption [5], [14]. Distribution-network pressure is influenced by ambient temperature and aggregate demand: Farzaneh-Gord and Rahbari [6] performed unsteady simulations of natural-gas distribution pipeline networks and demonstrated that ambient-temperature-driven demand variation produces measurable pressure drops at network nodes, with more severe drops occurring under higher-demand conditions. Industry technical literature further documents that high end-use demand can result in local low pressures in gas distribution mains sufficient to cause inadvertent shutdown of connected appliances, a phenomenon most pronounced during peak-usage periods such as morning and evening hours [15].

For commercial kitchen equipment connected to local low- or medium-pressure distribution mains alongside other simultaneous end-uses, this body of literature is consistent with the field observations motivating the present work: burner-supply pressure at the point of use is not necessarily constant, and equipment control systems that assume constant flame geometry may be more exposed to this variability than control systems whose sensing principle tolerates positional variation in the flame.

4 PROBLEM STATEMENT

The oven platform under study originally employed DSI with flame-rectification sensing. Field service records collected across the installed base indicated a recurring failure pattern: burners would shut down and register a loss-of-flame fault under conditions of natural-gas supply-pressure fluctuation, notably during periods of elevated network demand, even though visual and operational inspection confirmed that combustion had not actually ceased. Diagnosis attributed the fault to pressure-induced variation in flame shape and position causing the ionization electrode to lose a reliable sensing path within the flame envelope, consistent with the electrode-position sensitivity of ion-current sensing documented in the combustion-sensing literature [4], [7].

The operational consequence of this failure mode was a recurring need to dispatch a field technician to the customer site to diagnose the fault and re-regulate local gas pressure, at an estimated cost of approximately $800 per visit inclusive of airfare, ground transportation, lodging, and labor, occurring at a frequency of approximately once per month per affected site across a fleet distributed nationwide.

5 PROPOSED SYSTEM ARCHITECTURE

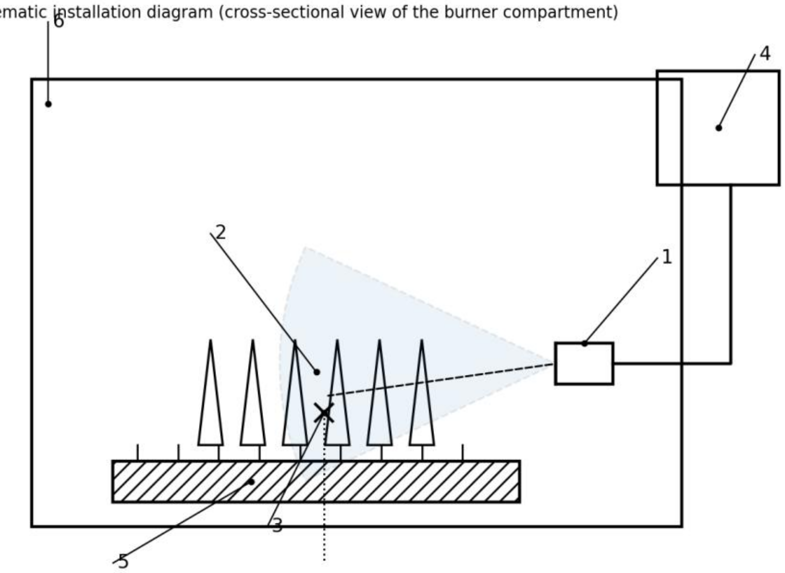
The redesigned burner safety-control architecture retains the existing spark-ignition subsystem and digital burner controller, replacing only the flame-sensing element and the corresponding logic path within the ignition-control module. The key architectural change is the substitution of the ionization sensing electrode with a fixed-position infrared optical flame sensor, selected and integrated in collaboration with the ignition-module manufacturer (on the ignition-control side) and with a specialized infrared flame-scanner manufacturer (on the optical-sensing side).

Under the revised architecture, flame confirmation no longer depends on the sensing element maintaining a precise physical position within the flame body. Instead, confirmation depends only on the flame remaining within the angular field of view of the IR sensor, a substantially less restrictive geometric constraint than the contact-based requirement of ionization sensing [4]. The ignition-control module continuously processes the signal received from the IR sensor and communicates flame-status information to the digital burner controller, which retains authority to command opening or closing of the gas valve exactly as in the original architecture. No change was made to the safety function of the system: loss of a genuine flame still results in immediate valve closure.

Figure 1 illustrates the installation of the infrared sensor within the burner compartment, in relation to the burner, the flame, and the position previously occupied by the ionization electrode. Figure 2 presents a block diagram of the resulting electrical and functional integration among the sensor, ignition-control module, spark electrode, digital controller, and gas valve.

FIGURE 1

Schematic installation diagram (cross-sectional view of the burner compartment)



1 - Infrared optical sensor
2 - Burner flame
3 - Former position of ionization electrode (replaced)
4 - Ignition control module
5 - Burner
6 - Burner compartment

Figure 1 - Schematic installation diagram of the infrared optical sensor within the burner compartment.

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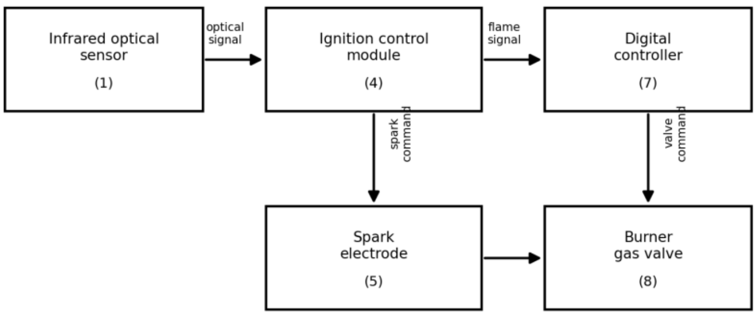
FIGURE 2

Block diagram of the electrical/functional integration



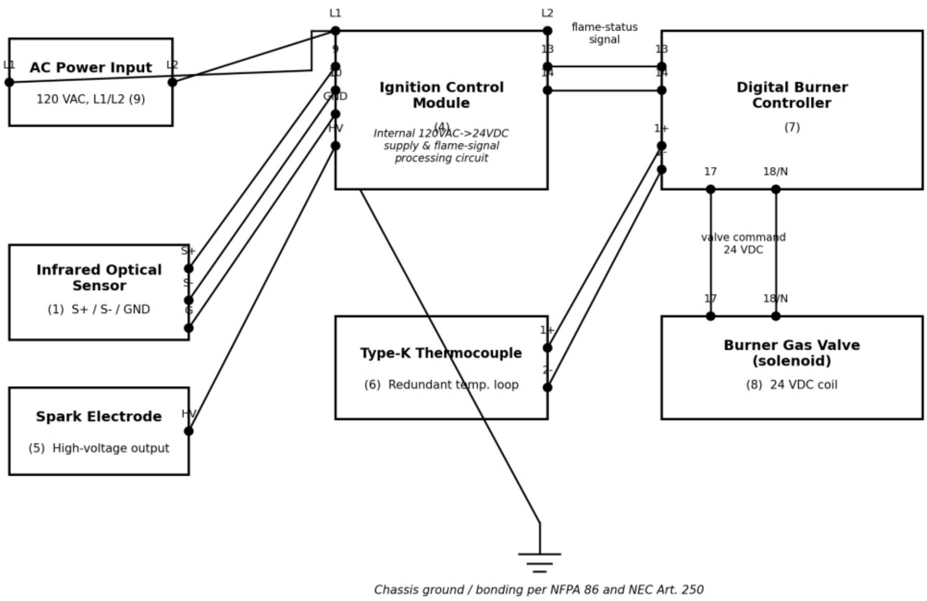
1 - Infrared optical sensor (flame detection)
4 - Ignition control module
5 - Spark electrode (initial ignition)
7 - Digital controller
8 - Burner gas valve

Figure 2 - Block diagram of the electrical/functional integration among system elements.

For completeness, Figure 3 presents a more detailed electrical schematic showing the power supply, control, and signal wiring among the AC power input, the ignition-control module, the infrared sensor, the spark electrode, the redundant thermocouple loop, the digital controller, and the gas valve, together with schematic terminal references and chassis-bonding requirements consistent with NFPA 86 and the U.S. National Electrical Code, Article 250 [16].

FIGURE 3

Detailed electrical schematic (power, control, and signal wiring)



1 - Infrared optical sensor 5 - Spark electrode 8 - Burner gas valve (solenoid)
4 - Ignition control module 6 - Type-K thermocouple (redundant loop)
7 - Digital burner controller 9 - AC power input (120 VAC)
Note: terminal numbers are schematic references for this study and do not correspond to any specific commercial component's terminal numbering.

Figure 3 - Detailed electrical schematic of power, control, and signal wiring among system components.

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6 FIELD IMPLEMENTATION

The redesigned architecture was deployed across eleven converted burner units at six distinct customer installation sites within the manufacturer's active U.S. customer base, replacing the original ionization-based sensing configuration on previously installed equipment. No modification to burner geometry, gas-train components, or valve hardware was required beyond the sensor and associated wiring/control-logic substitution, allowing the redesign to be applied as a field retrofit as well as a factory-installed configuration on new units.

7 RESULTS AND OPERATIONAL DATA

Following deployment, the affected sites were monitored for recurrence of the previously observed failure mode. The reported operational outcomes, drawn from internal service-dispatch and warranty records, are summarized below.

7.1 Reliability outcomes

A marked reduction in nuisance lockouts and false loss-of-flame events was observed across converted units, consistent with the architecture's reduced sensitivity to flame-position variation under fluctuating supply pressure. A corresponding reduction in equipment returns attributable to ignition-system malfunction was also observed.

7.2 Field-service outcomes

The recurring need to dispatch a technician for on-site gas-pressure re-regulation, previously required at a frequency of approximately once per month per affected site, was eliminated on converted units.

7.3 Cost impact

Based on an estimated per-visit cost of $800 (airfare, ground transportation, lodging, and labor) and a fleet of approximately 100 affected customer sites prior to conversion, the prior operating cost associated with this failure mode is summarized in Table 1.

Cost driver	Basis	Amount (USD)
Cost per on-site visit	Airfare, ground transport, lodging & labor	$800
Per client, per year	12 visits x $800	$9,600
Fleet of 100 clients, per month	100 x $800	$80,000
Fleet of 100 clients, per year	100 x $9,600	$960,000
Total over the prior 2 years (incurred)	$960,000 x 2	$1,920,000
Projected savings, next 2 years	Elimination of recurring pressure-regulation visits	up to $1,920,000

Table 1 - Estimated field-service cost impact associated with the addressed failure mode.

These figures represent internal operating estimates, corroborated by the company's service-dispatch logs and financial records, rather than an independently audited cost study; they are reported here as directional evidence of the operational significance of the failure mode addressed.

8 DISCUSSION

The case study illustrates a general engineering principle applicable beyond the specific equipment platform studied: where a flame-sensing method's reliability is contingent on

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precise mechanical or spatial positioning relative to a physically variable phenomenon (the flame), and where the operating environment is subject to variation in a parameter affecting that phenomenon's geometry (here, gas supply pressure), substituting a sensing method with a wider effective tolerance band can materially improve field reliability without altering the underlying safety function of the system. This is consistent with the combustion-sensing literature's characterization of ion-current sensing as more geometrically constrained than optical sensing approaches [4], [7], [9].

The approach reported here required no modification to burner hardware, gas-train components, or the fundamental safety logic of the digital burner controller, which may make it attractive as a retrofit strategy for existing installed fleets of commercial gas appliances exhibiting similar failure patterns, in addition to its applicability to new-equipment design. Given that documented pressure variability in gas distribution networks is a structural feature of network operation under peak demand rather than an anomaly [5], [6], [14], [15], equipment intended for installation on such networks may benefit from sensing architectures that are inherently tolerant of this variability.

A limitation of the present case study is that the reported cost and reliability outcomes are drawn from a single manufacturer's operational and service records rather than from a controlled, independently instrumented field trial. The absence of a matched control cohort operating with the original ionization-based configuration over the same period and under the same pressure conditions means that the magnitude of the reported improvement, while directionally consistent with the underlying physical mechanism described in Sections 2 and 3, cannot be attributed a formal statistical confidence level. Future work could usefully include controlled comparative field testing across matched cohorts of ionization-sensed and IR-sensed units instrumented with continuous gas-pressure logging, as well as broader application of the approach across other classes of commercial gas-fired equipment subject to variable supply-pressure conditions, such as water heaters, dryers, and industrial process burners, where the same underlying vulnerability has been reported [10], [15].

9 CONCLUSION

This paper reported an engineering case study in which ionization-based flame-rectification sensing was replaced with infrared optical flame supervision in a fleet of commercial gas-fired conveyor ovens, in response to a documented field-reliability problem associated with gas supply-pressure fluctuation, a condition well characterized in the natural-gas distribution engineering literature. The redesign was implemented without modification to burner hardware or to the underlying safety logic of the digital burner controller, and was associated with a marked reduction in nuisance shutdowns, a reduction in equipment returns, and elimination of recurring field-service dispatches for gas-pressure re-regulation, at an estimated avoided cost of up to $1,920,000 over a two-year horizon across the affected fleet. The approach is presented as a replicable engineering strategy applicable to other classes of commercial and industrial gas-fired equipment exhibiting similar flame-position-dependent sensing limitations.

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