Flame Plasma Surface Treating –What's it All About

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Introduction

Flame treaters are used in two basic applications, Pre-Treating and Post Treating.

Pre-Treating is defined as the application of flame to paper board prior to extrusion coating.

Post Treatment is defined as the application of a “controlled” flame to the PE coated paper board or directly to a film substrate.

Examples of some of the types of substrates flame treated arte shown in Table 1.

Table 1. Substrates Processed

SUBSTRATES PROCESSED	COATING
POLYMERS	
Polyolefin	**Primer topcoat**
BOPP	“
BOPP	“
PET	“
PAPER S	
Clay coated Kraft	**Silicone Topcoat**
SCK	“
Glassine	“
Poly-coated Kraft	“

Flame plasma surface treating systems either for Pre-Treatment or Post Treatment are designed to promote the adhesion of inks, coatings, laminations, etc.

Untreated polymers have a surface energy of 30 – 32 dynes/cm. In order to obtain acceptable adhesion, the difference in surface energy between the substrate and the topcoat should be at least 10 dynes/cm[1].

There are several adhesion promoting technologies that are used to raise the surface energy of the substrate, namely:

Table 2: Comparison of Adhesion Promotion Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Priming/Coupling agents	Good results	Recurrent replacement cost, environmental concerns
Corona	Widely used	Limited line speed
DIRECT FLAME	Higher treatment levels, No limit to line speed	Higher initial cost
Atmospheric plasma	Good results	High cost for carrier, limited line speed
Ozone, UV, Ozone + UV	Used for 3-D substrates	Line speed limited to 30 m/min (98 fpm)

Pre-Treatment

The main use of a flame treater for pre treatment of paper board is to promote the adhesion of PE extruded onto the board, or to promote the adhesion of a primer onto the board prior to extrusion coating.

The primary function of the flame treater is to add heat to the board and to burn off the tiny paper fibers present on the board surface.

The critical parameter in pre treatment is the amount of heat applied to the board. Flame chemistry, which will be covered later is not critical, although more and more companies are using this parameter as a quality control measure.

The amount of heat applied is a function of burner sizing. For lines speeds of 1000 FPM (325 m/min) approximately 15,000 Btu/Hr/In (148 kcal/mm/Hr) is usually required.

Higher line speeds require more heat. The relationship, however, is not proportional, but involves such parameters as line speed, ambient conditions, paper weight, coat weight, etc.

The amount of heat generated by the burner is controlled by the combustion air pressure.

Post Treatment

There are five key variables that optimize flame plasma surface treating for post treatment are:

- Flame Chemistry
- Amount of Plasma Generated
- Flame Geometry
- Distance of the Substrate from the Flame
- Dwell Time

Flame Chemistry

Flame chemistry is determined by the air/fuel ratio. In general, the stoichiometric ratio is *approximately* 10 air:1 part gas, for natural gas. It is 24:1 for LPG and 32:1 for butane.

The optimum flame chemistry is that which provides for an O_2 concentration, *in the flame plasma*, that is, after the combustion reaction, of 0.1% – 0.5%[1].

Simply setting the optimum air/fuel ratio will not assure optimal surface treatment for the following reasons. In the combustion industry, air and fuel are measured by volume, however, the combustion reaction is based on mass (gram or pound mole). Controlling air and gas on a volume basis does not take into account the change in O_2 concentration in the air due to combustion air temperature and humidity. A combustion air blower provides a fixed volume of air regardless of the air density, which will be affected by temperature and the humidity of the air. Higher temperature air contains less mass of O_2, if the air is humid, the H_2O will displace some of the oxygen. If the flame chemistry is optimized on a cool dry day, on a hot, humid day it may not at the optimal ratio.

Similarly, gas composition changes based on the gas field from which the gas is drawn. Again, optimizing at one gas composition does not mean optimal flame chemistry at a different composition.

The change in the O_2 concentration with air temperature and humidity is illustrated in Table 5. Table 6 illustrates the differences in gas composition based on the gas field.

Table 3: Effect of Temperature & Humidity on O_2 in Air

Temperature (^{O}F)	Humidity (%)	O_2	N_2	Ar_2, CO, H_2	H_2O	Density ($lb./ft^2$)
60	*0*	*20.99*	78.03	0.98	0	0.07632
60	80	20.70	79.64	0.97	1.4	0.07592
60	100	20.62	76.67	0.96	1.75	0.07581
90	20	20.79	0.97	0.97	0.95	0.07189
90	80	20.19	75.06	0.90	3.81	0.07111
90	*100*	*19.99*	74.32	0.90	4.76	0.07086

Table4: Gas Composition from Different Gas Fields

Component	Birmingham	Ohio	Pittsburg	Alaska
Methane (CH_4)	90.0	94.1	83.4	99.6
Ethane (C_2H_6)	5.0	3.0	16	-----
Propane (C_3H_8)	-----	0.4	-----	-----
Volume air/ Volume gas (Stoichiometric)	10.47	10.72	11.70	10.52

First generation flame treaters attempted to compensate for the changes in flame chemistry due to differences in air temperature, humidity and gas composition by the use of flow meters. However, flow meters cannot compensate for these differences in combustion air temperature and humidity since they measure volume, not mass flow. Changes in gas composition similarly cannot be compensated for by flow meters.

Because of these limitations, first generation flame treaters were not reliable, in terms of repeatability and consistency of treatment.

An in-line flame plasma analyzer was developed in the 1980's as an effective control device to overcome these limitations. The analyzer operates as follows:

A sample of the air/gas mixture is fed into the first stage catalytic cell at a fixed rate. The catalytic cell is maintained at approximately 650 ^{O}C (1200 ^{O}F). The sample ignites, burns, and the products of combustion (POC's) flow into the analyzer cell, maintained at a lower temperature and which incorporates a ceramic/platinum sensor produces an electrical voltage proportional to the

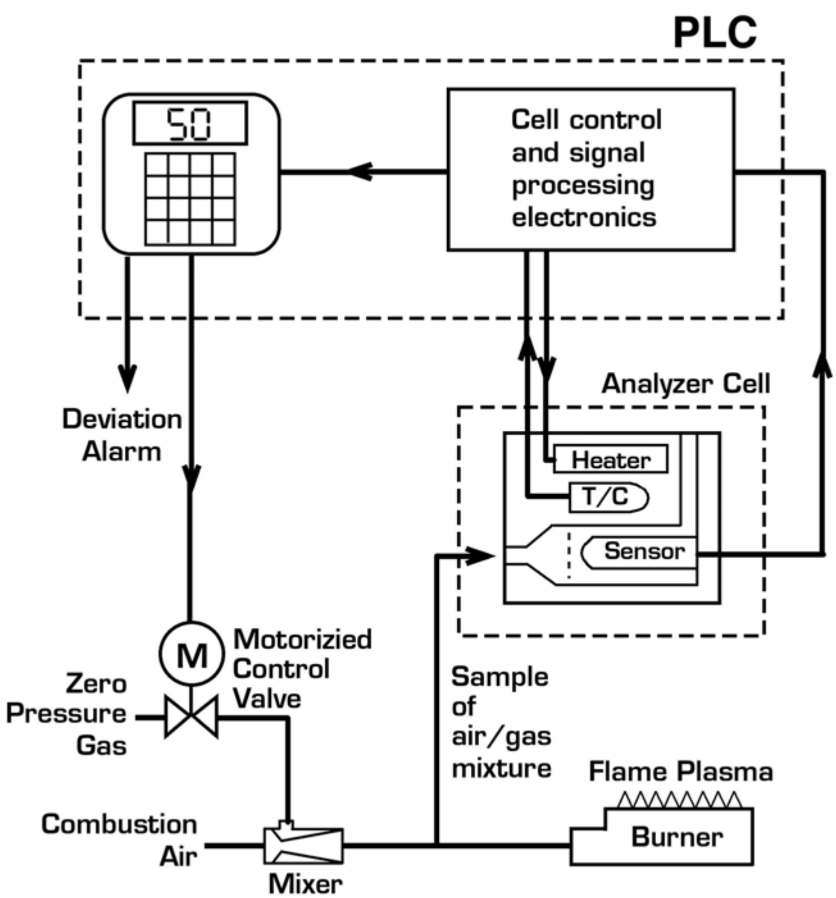
amount of excess O_2 or excess hydrocarbon present in the POC's. The signal is amplified, conditioned and linearized.
A discrete step function occurs when there is no excess O_2 or excess hydrocarbon (unburnt fuel) is present in the POC's. This is the stoichiometric ratio of oxygen to fuel.

The signal is in used as an input to the PLC which has a control loop output to operate a gas flow control valve, open or close, to maintain the specified set point amount of excess O_2 in the POC's.

This value depends on the specific substrate, line speed and treatment level required and is best determined by trials

A schematic representation of the analyzer is shown in figure 1.

Figure 1: Flame Plasma Analyzer



In the most recent development, control of the flame chemistry has been enhanced by the use of mass flow meters for both air and gas together with the use of a flame analyzer, used to measure and control the amount of excess hydrocarbon (gas) or O_2 in the flame plasma. This arrangement allows for very fast response time as well as for real time calibration of the mass flow of combustion air and fuel gas. This is critical when the line starts up at 100m/min (328 fpm) and quickly ramps up to 1000m/min (3280 fpm). The ability to quickly achieve optimum flame chemistry minimizes production looses.

Plasma Generation

Critical issues in the design of the flame treater for post treatment are:

I) Burner design to prevent laning or striations.

II) Burner design and control scheme for operation at line speeds of
100m – 1000m/min

III) Combustion noise

Laning is defined as a periodic variation in the treatment level of a polymer substrate in the cross machine direction. Researchers have indicated that laning is due to the spacing of the flames in the treatment burner and the firing rate of the burner.

There are two types of burners used for flame treating.

Ribbon burners consist of a series of stainless steel “ribbons” the crimp and angle of which are specifically designed for the type of substrate & substrate geometry inserted in a high capacity extruded aluminum burner, to insure uniformity of treatment and totality of treatment.

A ribbon stack is shown in Figure 2. Figures 3 and 4 show a cross section of a ribbon burner and a photo of the (8) port wide slot burner that was used in this high speed installation, Fig. 4.

Figure 2: Typical Ribbon Burner Stack

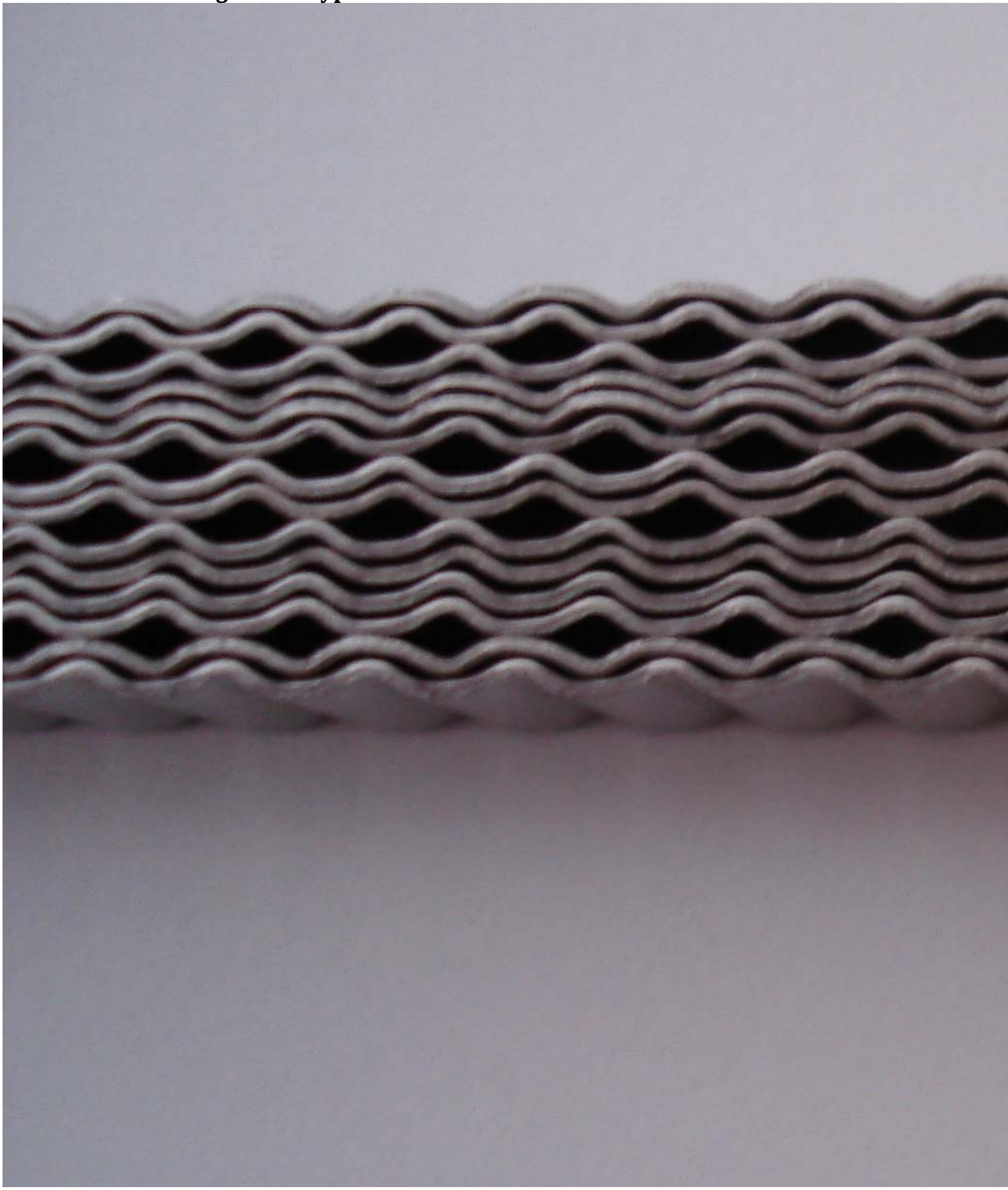


Figure 3: Ribbon Burner Cross Section

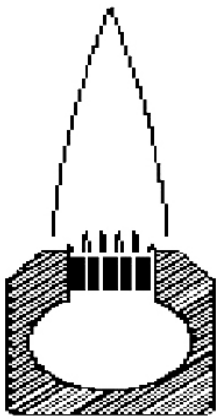
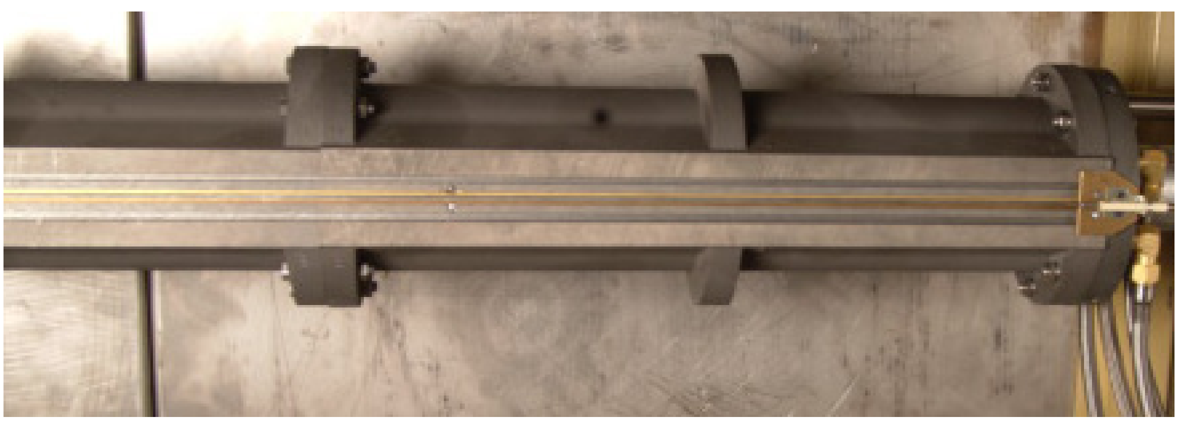
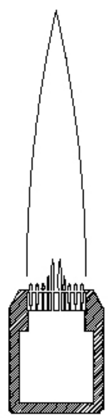


Figure 4: High Capacity (8) Port ribbon Burner



The second burner type is the drilled port burner which consists of a CNC drilled port brass inserted in an aluminum body[2] is shown in figure 5.

Figure 5: Drilled Port Burner Cross Section[3]



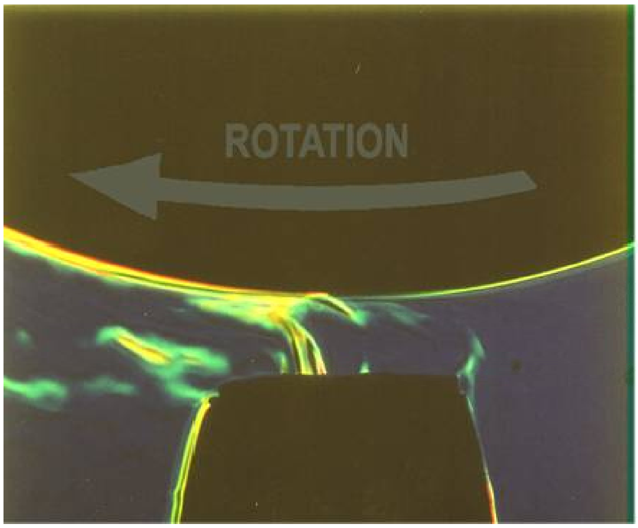
Ribbon burners are inherently backfire proof. This means that if the velocity of the air gas mixture is less than the rate of flame propagation, the flame will not travel back to the burner manifold and burn. This is achieved in a ribbon burner by the cooling effect on the flame as it travels backward through the ribbon stack. The flame is cooled below minimum flame temperature to sustain ignition.

The manufacturer of the drill port burner makes a similar claim.

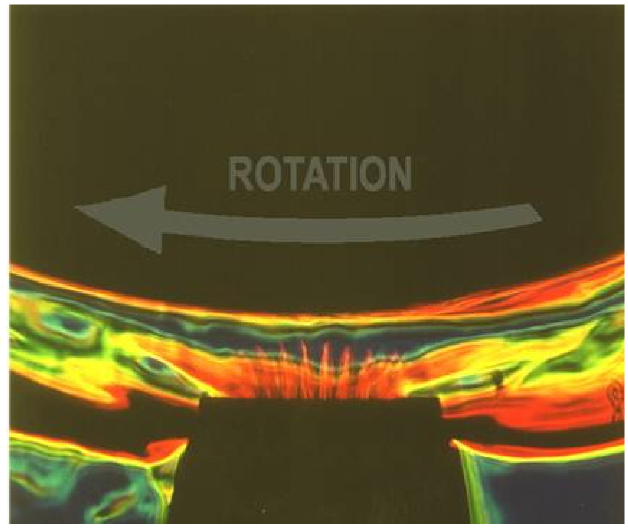
To address these three issues, burner design to prevent laning, design and control philosophy for operation over a wide range of machine speeds and combustion noise, a ribbon burner was designed in a wide slot configuration which proves sufficient plasma at 1000 m/min and the flame geometry to eliminate striations.

A comparison of a 2 port narrow slot ribbon burner with the 8 port wide slot is shown in figure 6**.**

Figure 6: Schlering Image of (2) Port Ribbon Burner compared to (8) Port Wide Slot



(2) Port Ribbon Pattern



(8) Port Ribbon pattern

It is apparent from these Schlering images that at high line speeds the (2) port ribbon does not provide as much plasma as does the (8) port. More importantly, the (8) port geometry is such that laning is minimized when compared to a (2) port firing at the same rate.

At high line speeds, those in excess of 800 m/min (2624 fpm), an alternative to the wide slot burner is the use of two or more burners. This adds cost, unnecessary complexity and the need for additional maintenance to the flame treater.

Another critical design issue that had to be dealt with for this project was how to operate the treater from a line speed of 100 m/min (328 fpm) up to 1000m/min (3280 fpm). At low line speeds, the plasma output required is approximately 100 Kcal/Hr/cm (1000 Btu/Hr/In), at high line speeds as much as 3000 Kcal/Hr/cm (30,000 Btu/Hr/In).

One approach is to use multiple burners (at least 4, perhaps as many as 6), this would be the case if a drilled port burner would have been used, since the drilled port burner is not capable of providing sufficient output without laning and might not even be able to treat the substrate, at the specified high end line speeds.

However, the use of an (8) port wide slot burner with a unique air/gas mixing control strategy allowed the use of only two burners, firing at 50% of maximum capacity at 1000 m/min. This provides the capability to increase line speed 30% in the future without any change to the flame treating system.

When firing a burner, whether a ribbon burner or a drilled port burner, against a back up roll at a distance of 6-12.5 mm (1/4" – 1/2"), combustion harmonics or noise, is usually manifested. The resolution of noise is difficult and this is where experience in flame treating is critical, knowing what to do to eliminate the noise.

The proper design of the exhaust system is critical in eliminating and/or minimizing combustion noise. Treater design to interfere with the resonance created by the combustion of the air/gas mixture plays a critical role in noise suppression.

The elimination or at least the attenuation of the noise is usually accomplished by a variation in the ribbon pattern and/or the interruption of the resonating column by insertion of baffles or other means.

Flame Geometry

In order to obtain uniformity of surface treatment, the plasma must react with the surface of the substrate evenly, without discontinuity. This uniformity of treatment is achieved by use of a ribbon burner, which provides an extremely uniform flame front geometry, without laning.

Distance of the Substrate from the Flame

Average distance of the substrate to the flame varies from 6 – 12.5 mm (1/4' – ½"). The optimum distance is a result of field trials and in this project turned out to be 8mm. However, noise and laning must be considered in determining the optimum distance.

Dwell Time

The substrate needs to be in contact with the flame plasma for enough time to affect the surface. This is achieved by providing a burner that can produce sufficient plasma in a uniform manner. At line speeds of 1000 m/min 3280 fpm), the burner must be capable of providing 3000 Kcal/Hr/cm (30, 000 Btu/Hr/In) without laning.

A single (8) port ribbon burner can provide this level of plasma generation, uniformly and without laning.

A schematic of the web path through the flame treater is shown in figure 7. The burner, nip roll, water cooled back up roll, heat shield and idler rolls are shown.

A photo of the flame treater is shown in figure 8.

Figure 7: Web path Through Flame Treater Station

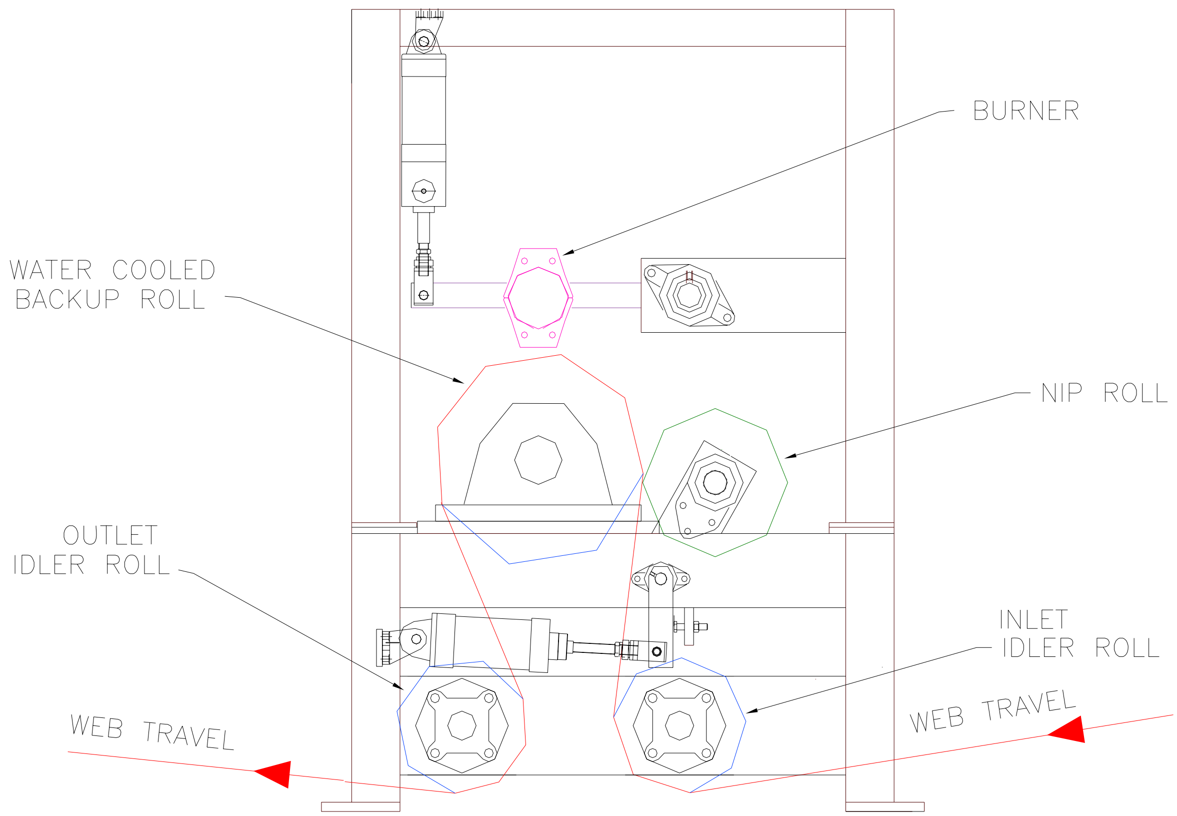


Figure 8: High Speed Flame Treater

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2. Markgraf, D.A., “New Burner Technology for Converting Applications”, TAPPI PLACE New Technology Showcase, August 2003

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2007 PLACE Conference

September 16-20

St Louis, MO

What's it all about---Adhesion Promotion using Flame Plasma

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Sales Director

Flynn Burner Corporation

What's Flame plasma treatment ?

It’s NOT.....

Flame Plasma Treatment is…

Using the reactive species in the

products of combustion (flame plasma)

to increase the surface energy of the

substrate

Reactive Species in the Flame Plasma

- (OH^-) - Hydroxyl Free Radical
- ($COOH^-$) - Carbonyl
- (O=C-O) - Carboxyl
- (R-O-R) - Ether
- (R-C=O-OR’) - Ester

Reactive Species in the Flame Plasma

- (O) + (O^-) - Oxygen atoms & ions
- (e^-) - Free electrons

What is adhesion promotion all about

?????

Bonding

"Kevin and his Dad are bonding."

Comparison of Adhesion Promotion Technologies

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
Primers	Excellent results	Replacement cost, Environmental issues
Corona	Widely used	Limited line speed
DIRECT FLAME	**No limit to line speed**	**Higher initial cost**
Atmospheric plasma	Good for hard to treat substrates	Cost & availability of carrier gas

Flame, Corona & Atmospheric Plasma

- POLARIZE the surface of the substrate by:

- OXIDIZING the surface by adding "functional groups"

- ALTERING the electron distribution & density AT THE SURFACE

Reactive Species in the Flame Plasma

- (OH^-) - Hydroxyl Free Radical
- ($COOH^-$) - Carbonyl
- (O=C-O) - Carboxyl
- (R-O-R) - Ether
- (R-C=O-OR’) - Ester

Reactive species in the POC's (Plasma)

- (OH^-) - Hydroxyl free radical
- (COOH) - Carboxylic

Pre-Treatment---What is it?

- Application of flame to a substrate, usually paper board, prior to extrusion coating

Key Variables in Pre-Treatment

- Flame geometry
- Amount of plasma (heat) generated
- Distance of the burner from the part
- Flame Chemistry

Key Variables in Pre-Treatment

- Flame geometry

Provides uniformity of treatment across the sheet

Key Variables in Pre-Treatment

- Amount of plasma (heat) generated

  1) Burns off the small fibers &

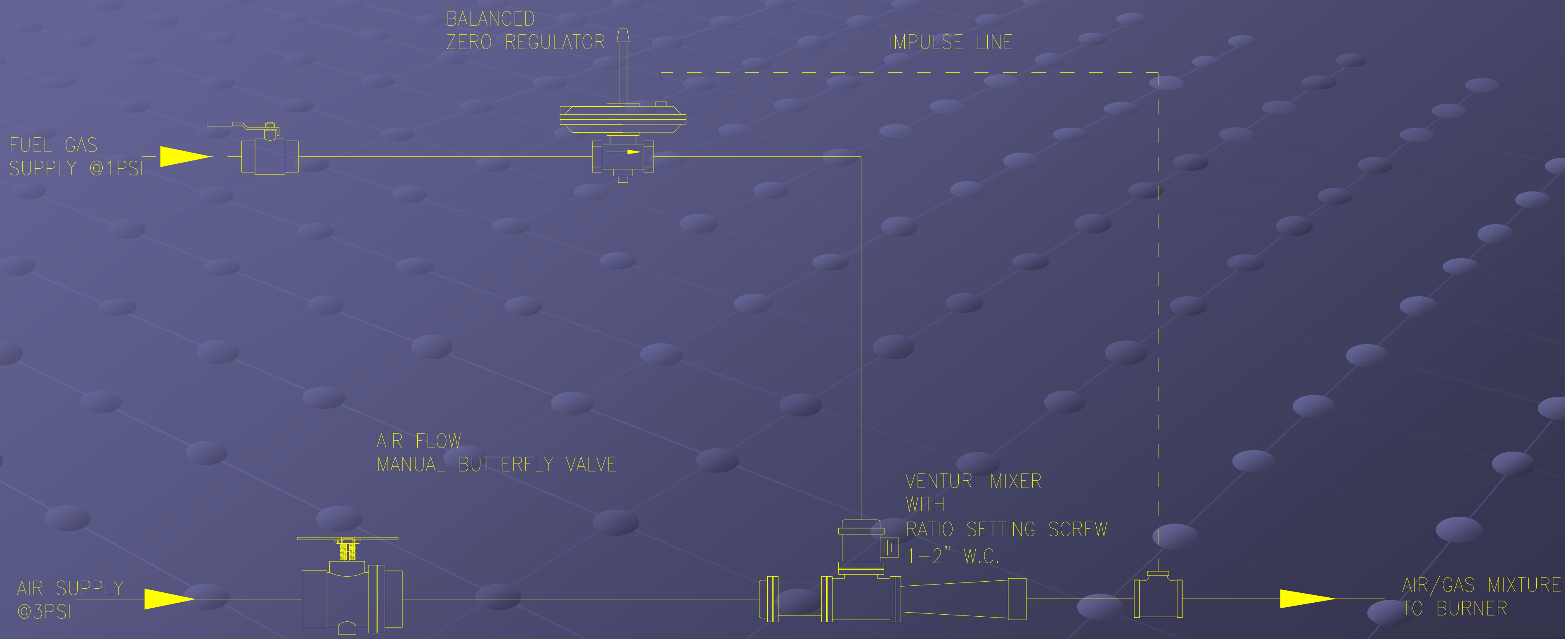
  2) Hot board enhances PE adhesion

Key Variables in Pre-Treatment

- Distance of the burner from the substrate

  ~1/2" (12mm) – 3" (75mm)

Control System For a Pre-treater
Zero Gas Pressure Regulator w/ Manual Air Control



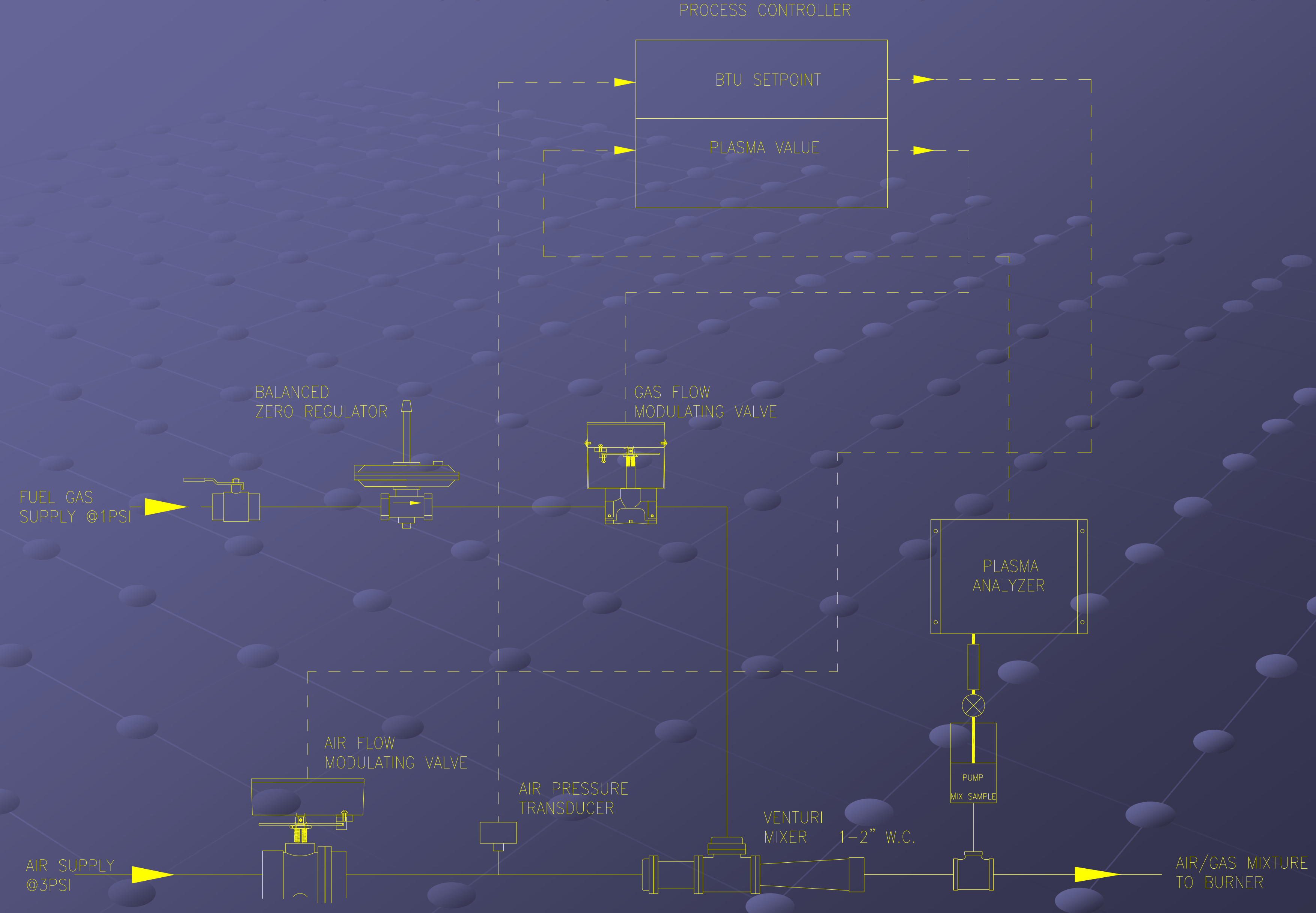
Key Variables in Pre-Treatment

- Flame Chemistry

Adds reactive species to the surface of the board which enhances PE adhesion

Control System

ZERO REGULATOR WITH PLASMA ANALYSIS



Post Treatment---What is it?

Application of flame to…..

- PE surface of paper board
- Directly to polymer films, (BOPP, OPP, foils, laminated structures, complex film structures

Key Variables in Post Treatment

- Flame chemistry (air/gas ratio ~ 10:1)
- Flame geometry
- Amount of plasma generated
- Distance of the burner from the part

Flame Chemistry

- Optimum flame chemistry

0.1 – 0.5% O_2 in the flame plasma

(in the post combustion gases)

Flame Chemistry

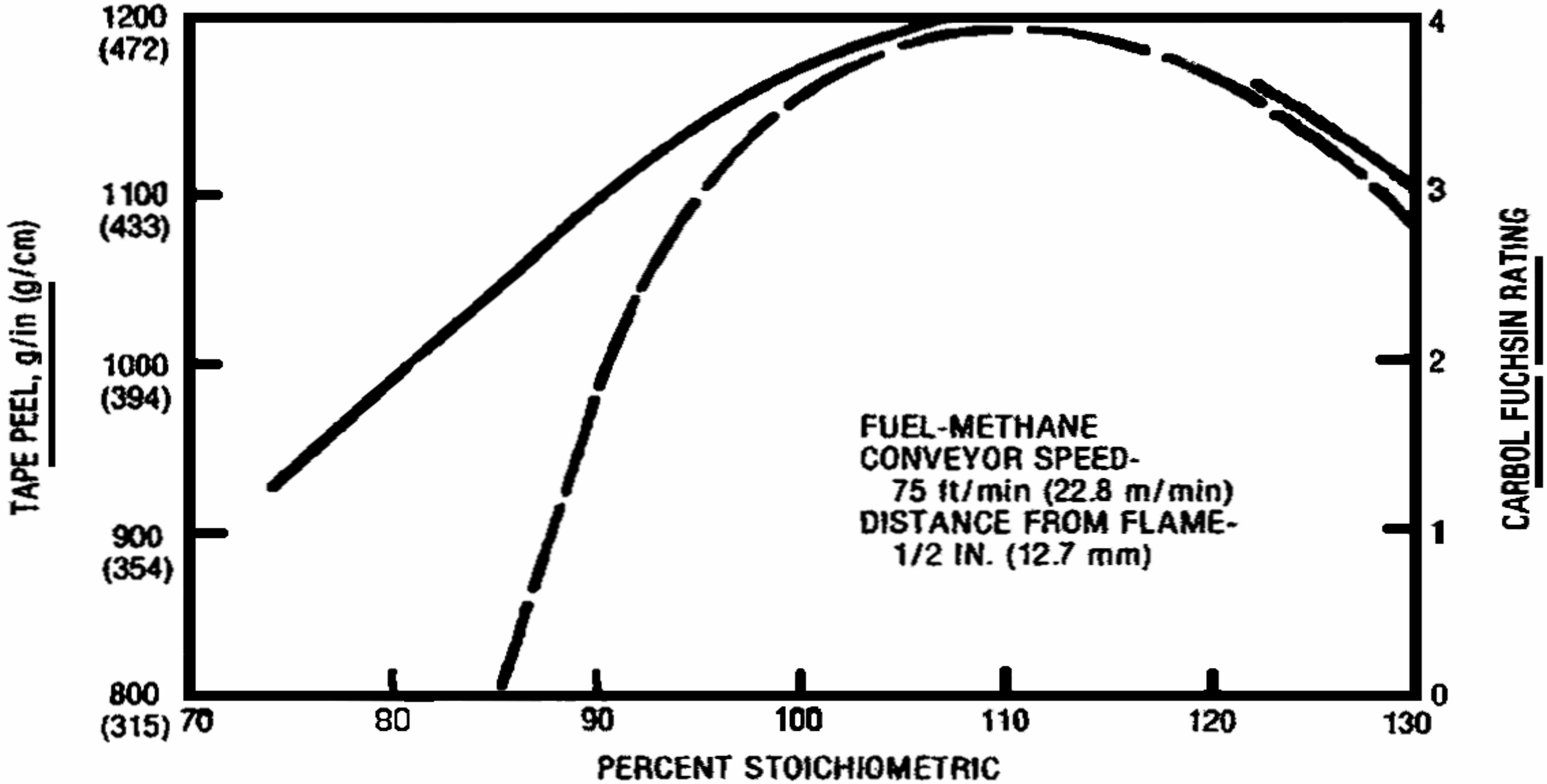


FIGURE 1

EFFECT OF AIR/GAS RATIO ON TREATMENT LEVEL

Flame Chemistry

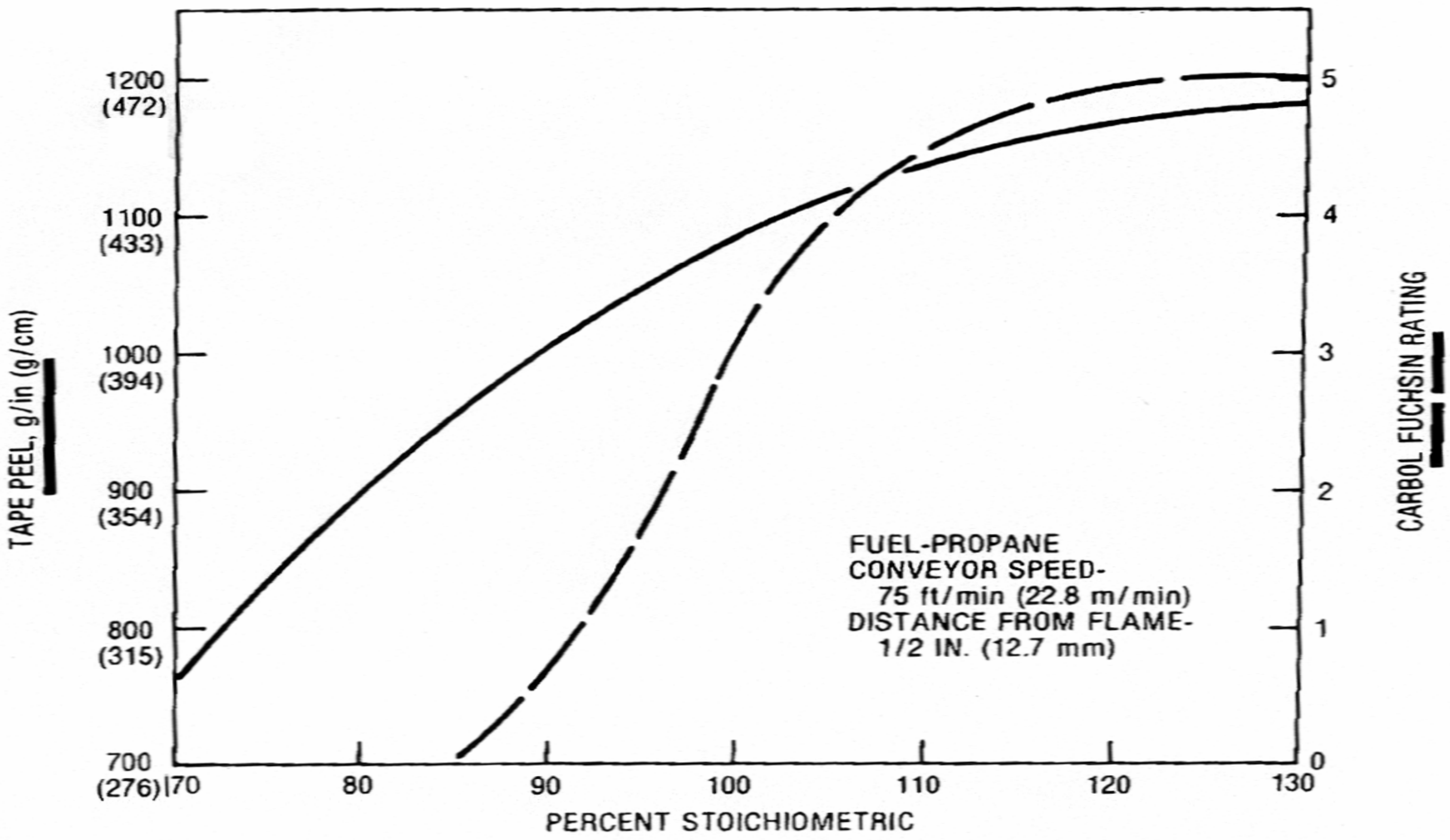


FIGURE 1A

EFFECT OF AIR/GAS RATIO ON
TREATMENT LEVEL

What affects flame chemistry ??

- Combustion Air

- Fuel

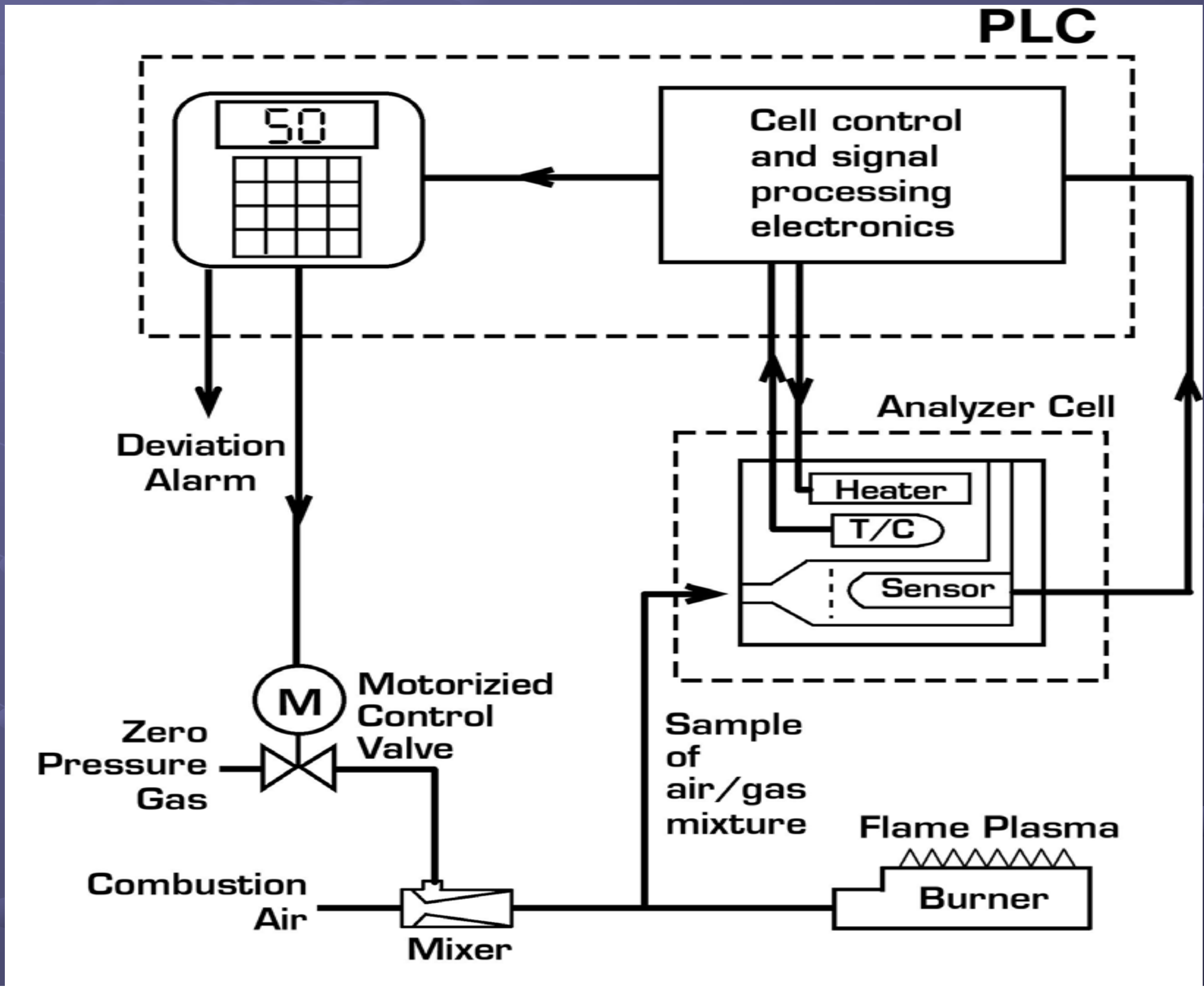
Effect of temperature & humidity on O_2 in combustion air

TEMPERATURE °C (°F)	Humidity (%)	O_2 (%)
16 (60 °F)	0	**21**
32 (90 °F)	100	**20**

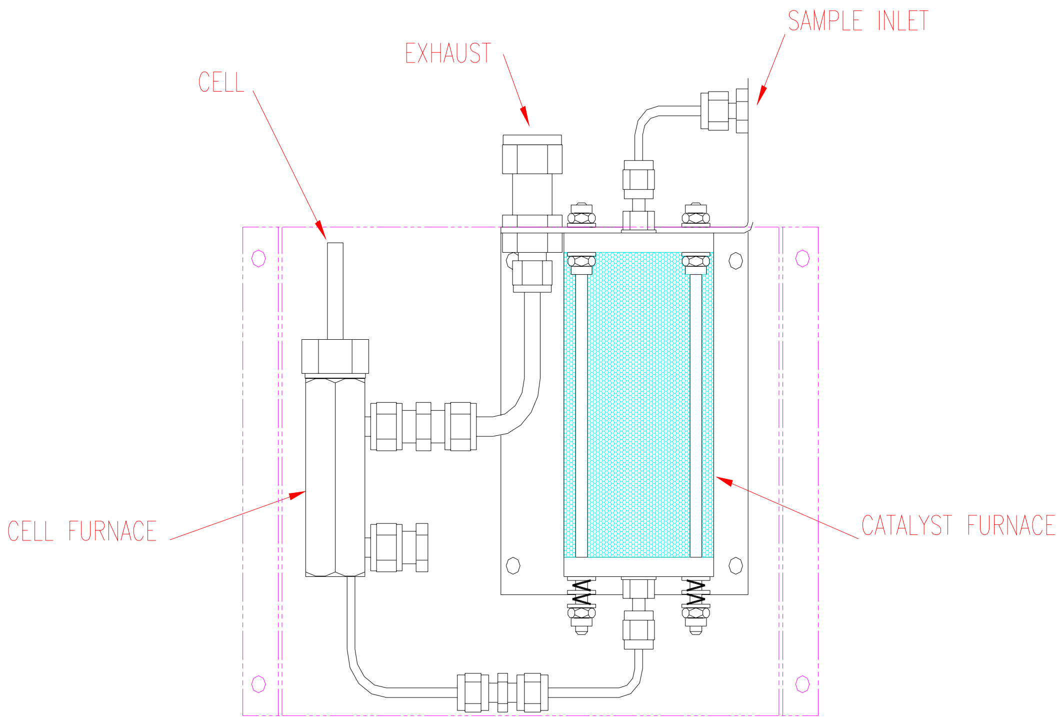
Gas composition from different gas fields

COMPONENT	North Sea	Algeria	Alaska
Methane CH_4	90 %	94%	99%
Ethane C_3H_6	5%	3%	-----
Stoichiometric ratio	10.5	10.7	10.5

Flame Plasma Analyzer



Flame Plasma Analyzer



Aother Method to control flame chemistry

Flame Temperature

Measures the temperature of a small pilot flame and uses an algorithm relating flame temperature to air/fuel ratio

Flame Geometry & Amount of Plasma Generated

Determined by:

- Burner design

……..Ribbon

……..Drilled port

Flame Geometry

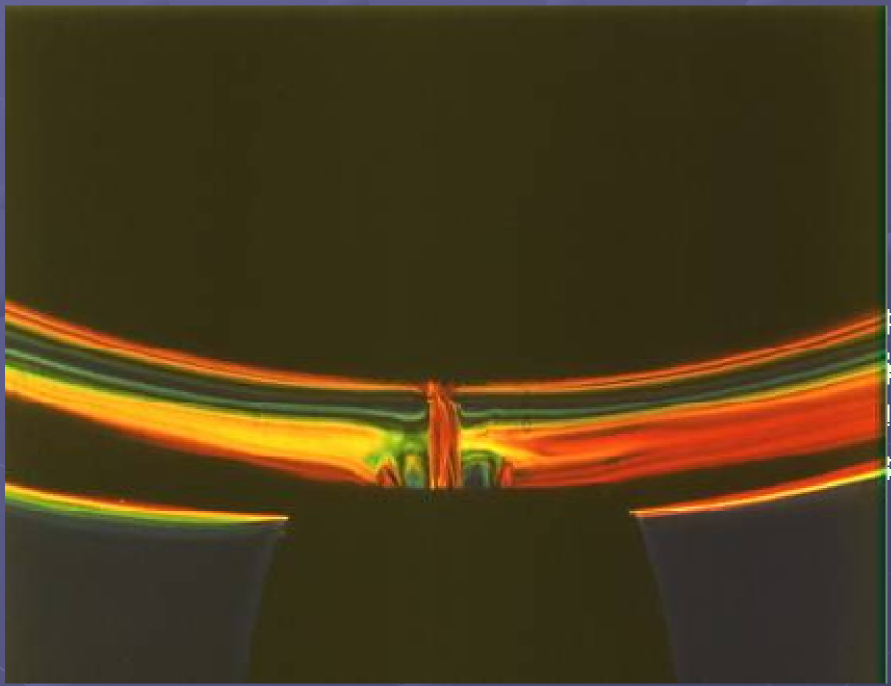
And….it's critical because it affects

THE UNIFORMITY of TREATMENT

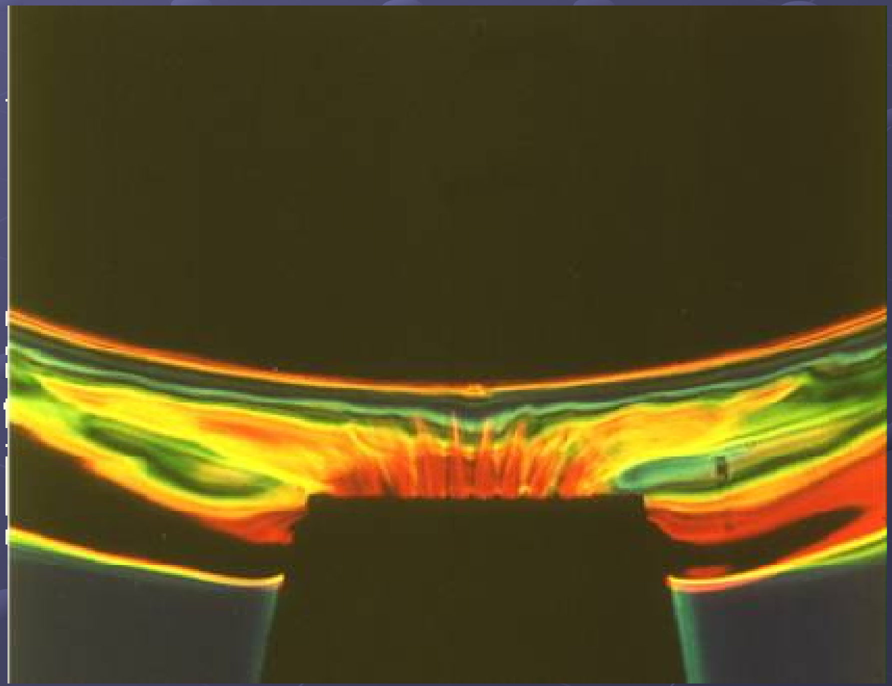
(Laning/Striations)

Flame Geometry Studies

0 speed



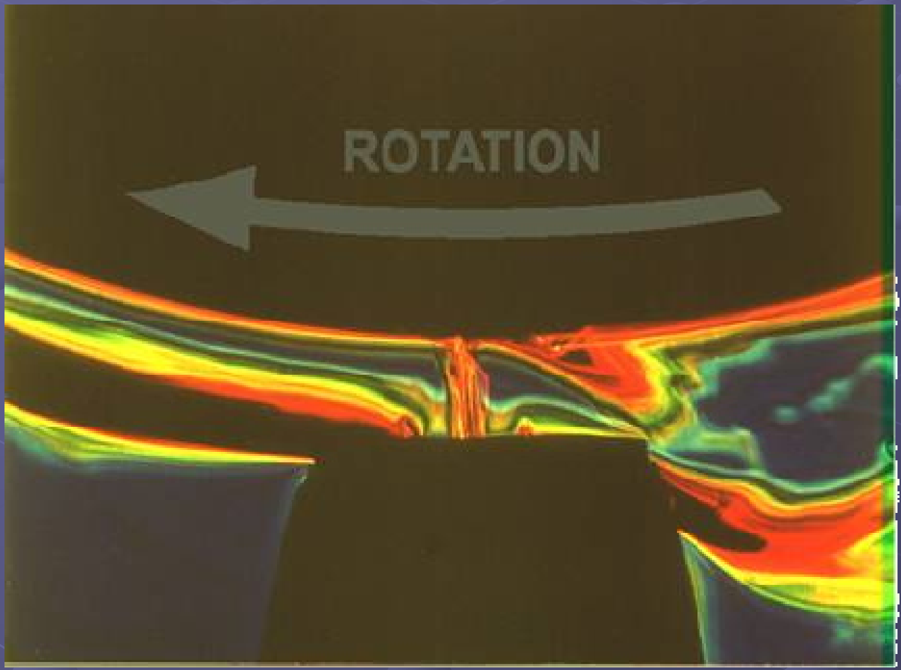
2 PORT

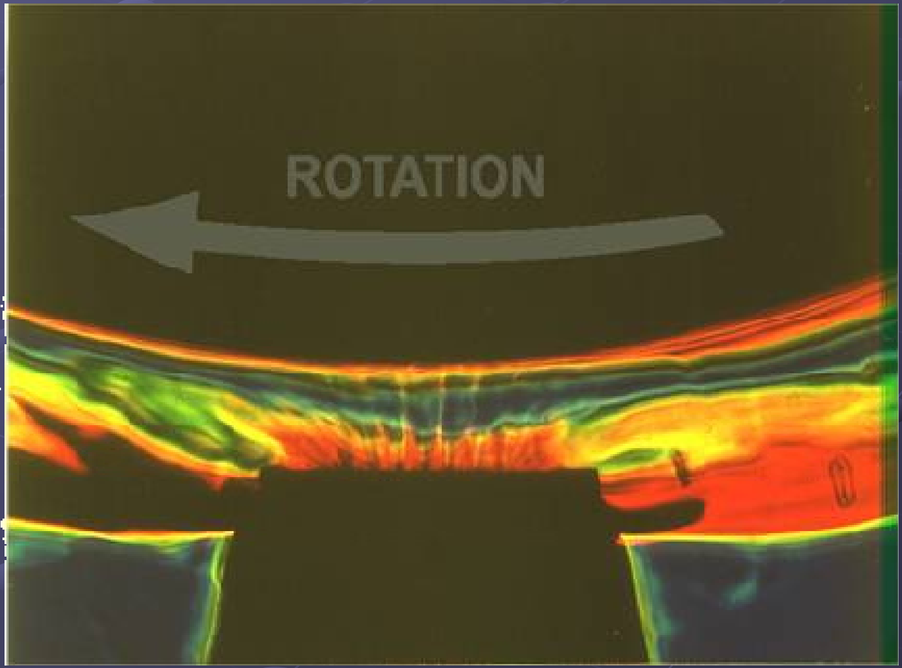


8 PORT

Flame Geometry Studies

Low



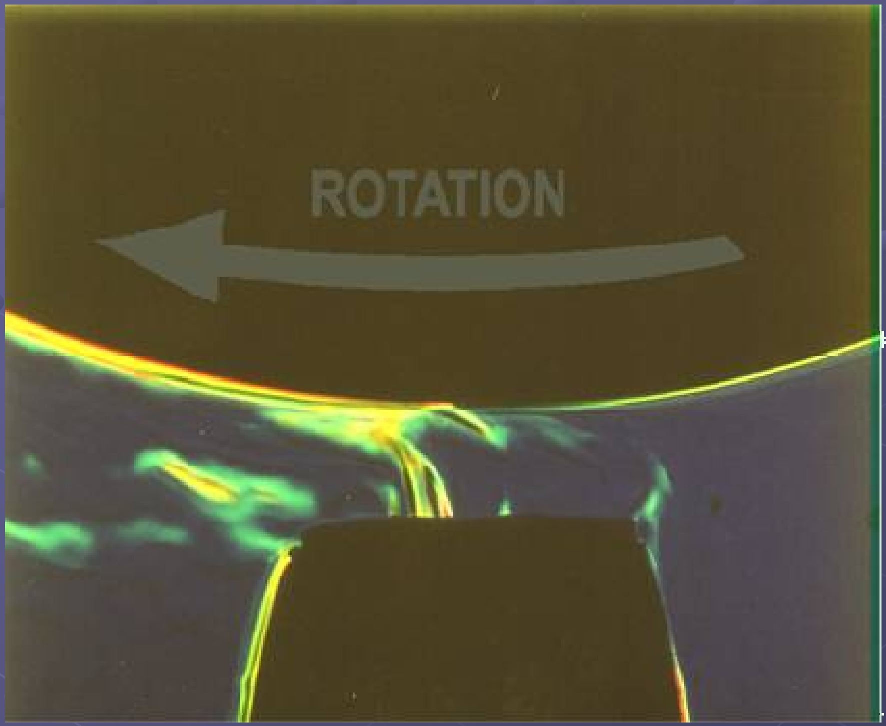


2 PORT

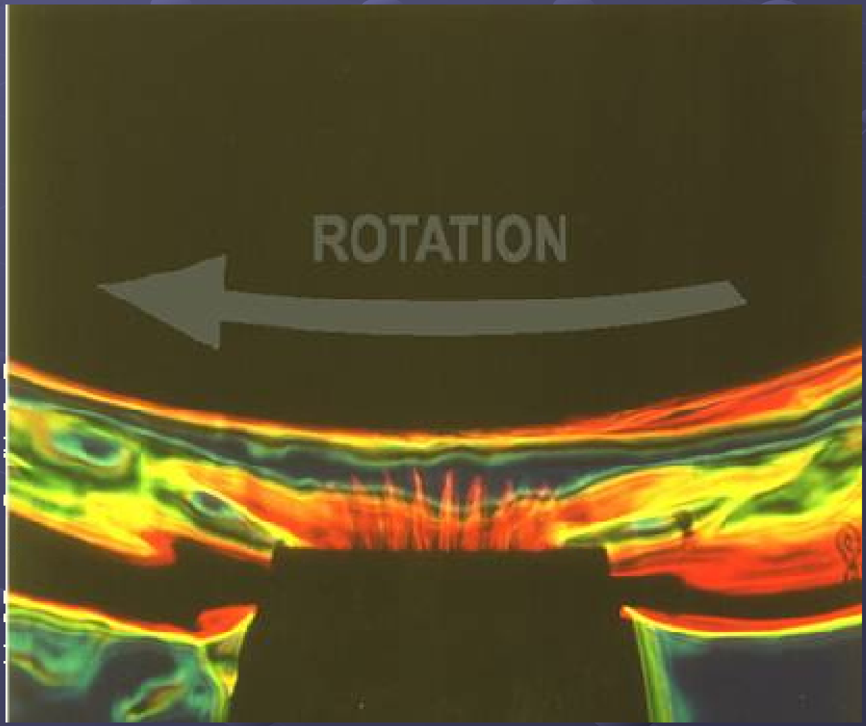
8 PORT

Flame Geometry Studies

High



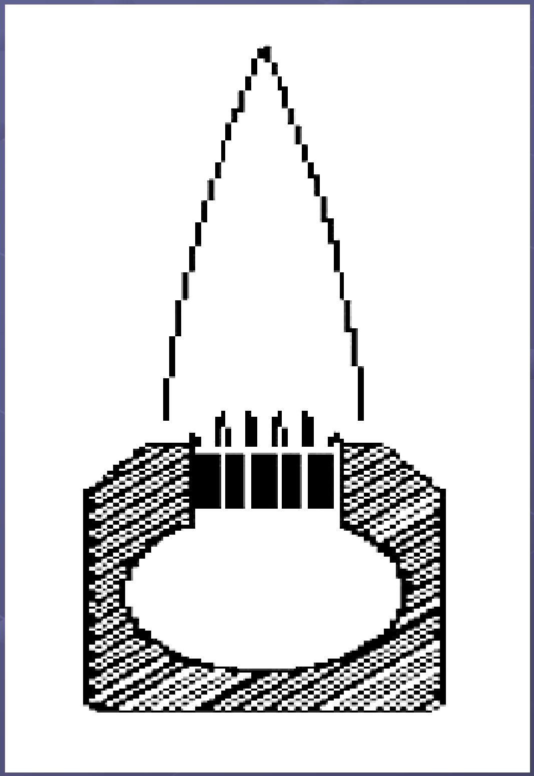
2 PORT



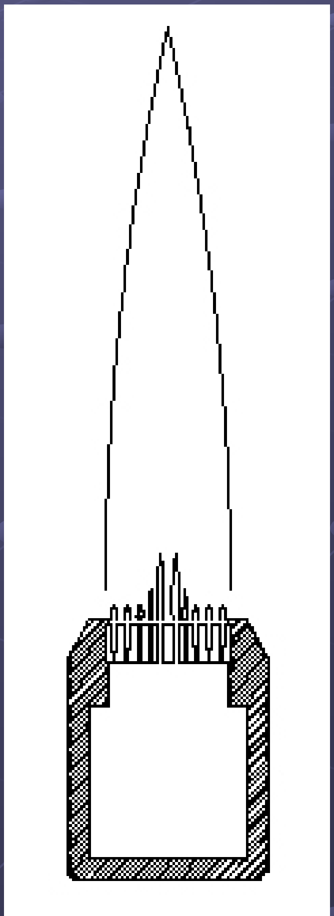
8 PORT

Burner Types

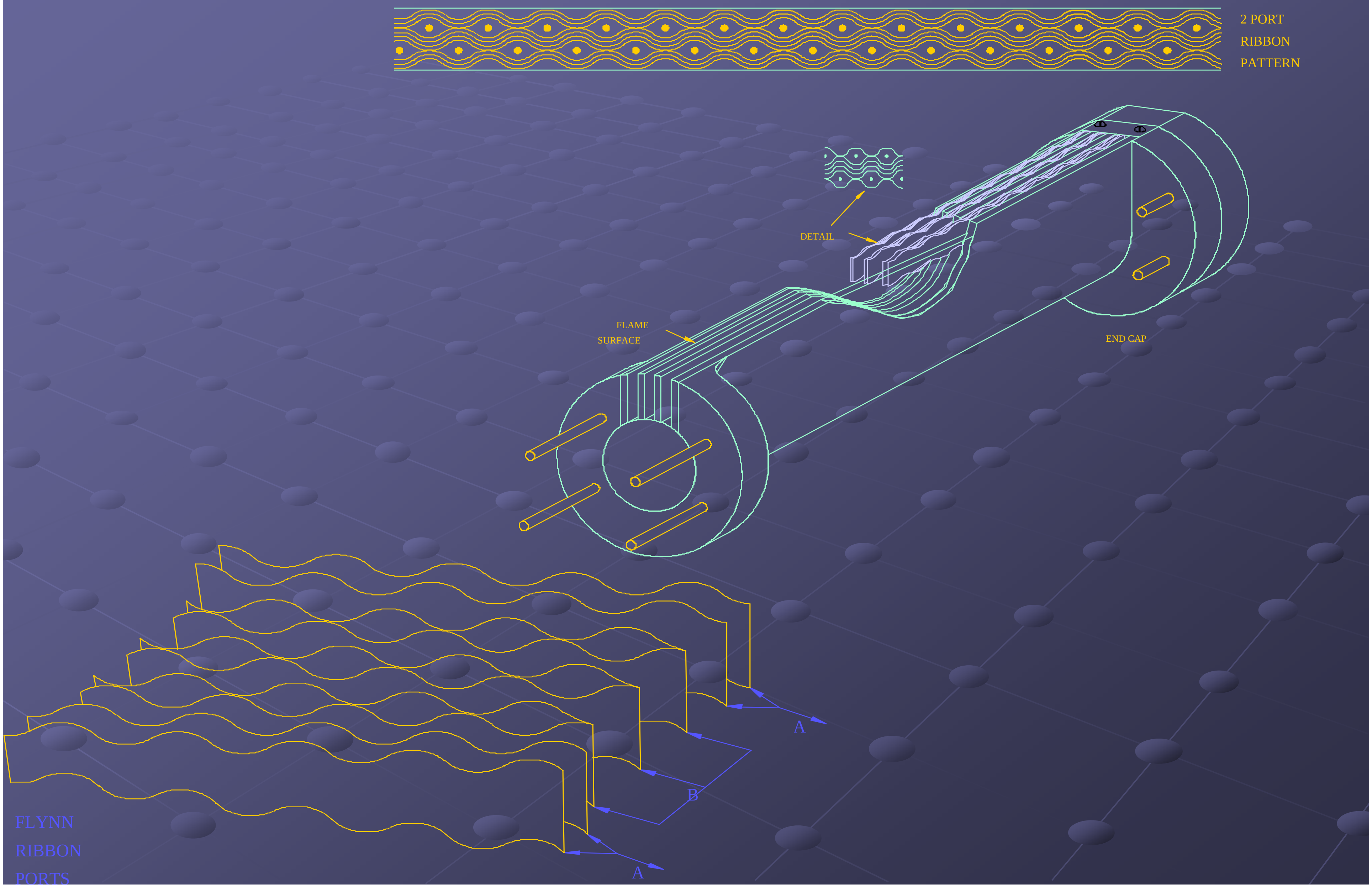
Ribbon



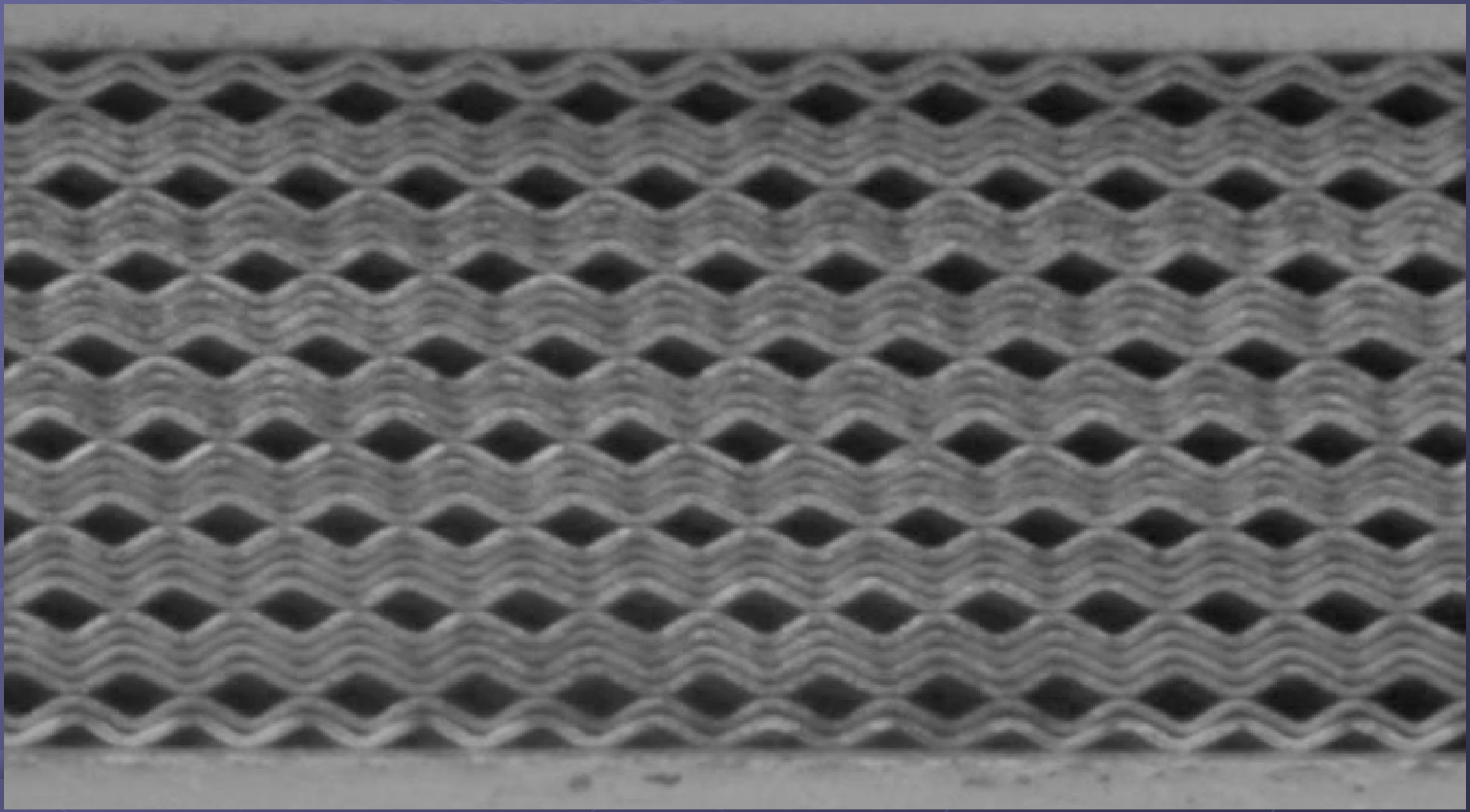
Drilled Port



RIBBON

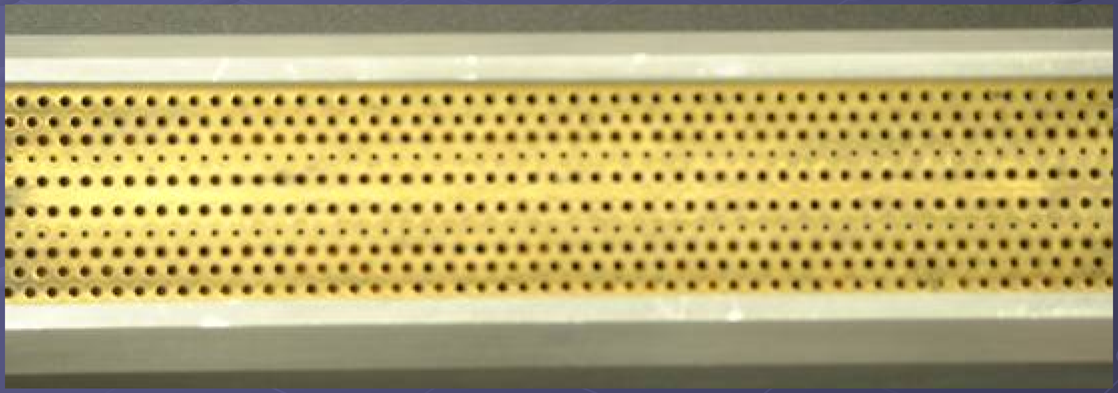

2 PORT
RIBBON
PATTERN
DETAIL
FLAME
SURFACE
END CAP
A
B
A
FLYNN
RIBBON
PORTS

Aluminum Burner
(8) Port



Aluminum Burner
(4) Port

Drilled Port



Advantages of Ribbon vs. Drilled Port Burner

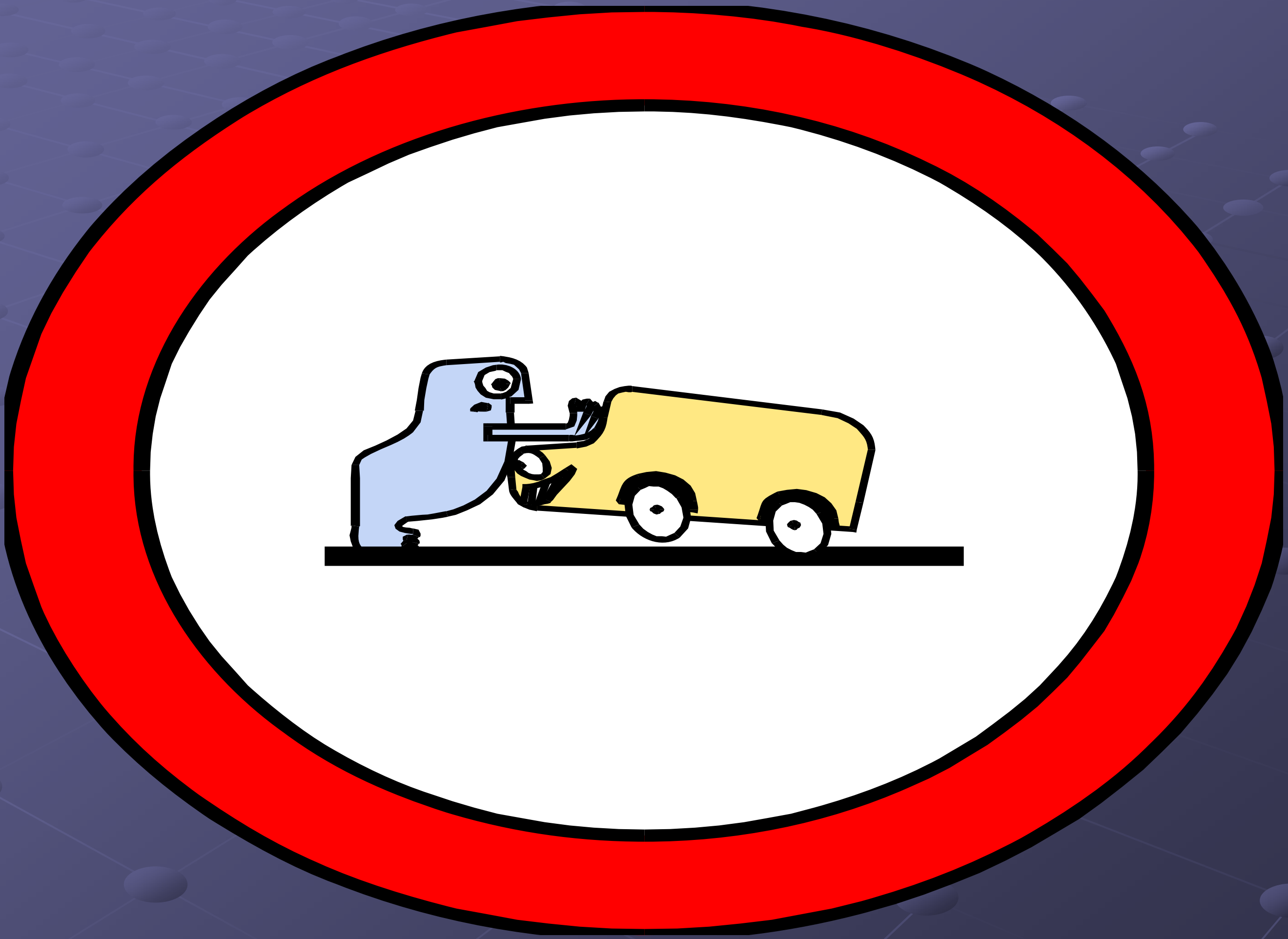
RIBBON BURNER PROVIDES:

- More Energy

(up to 200 kcal/mm/20,000BTU/In) without striations

- More Uniform Treatment

Distance Burner to Part



Distance - Burner to Part

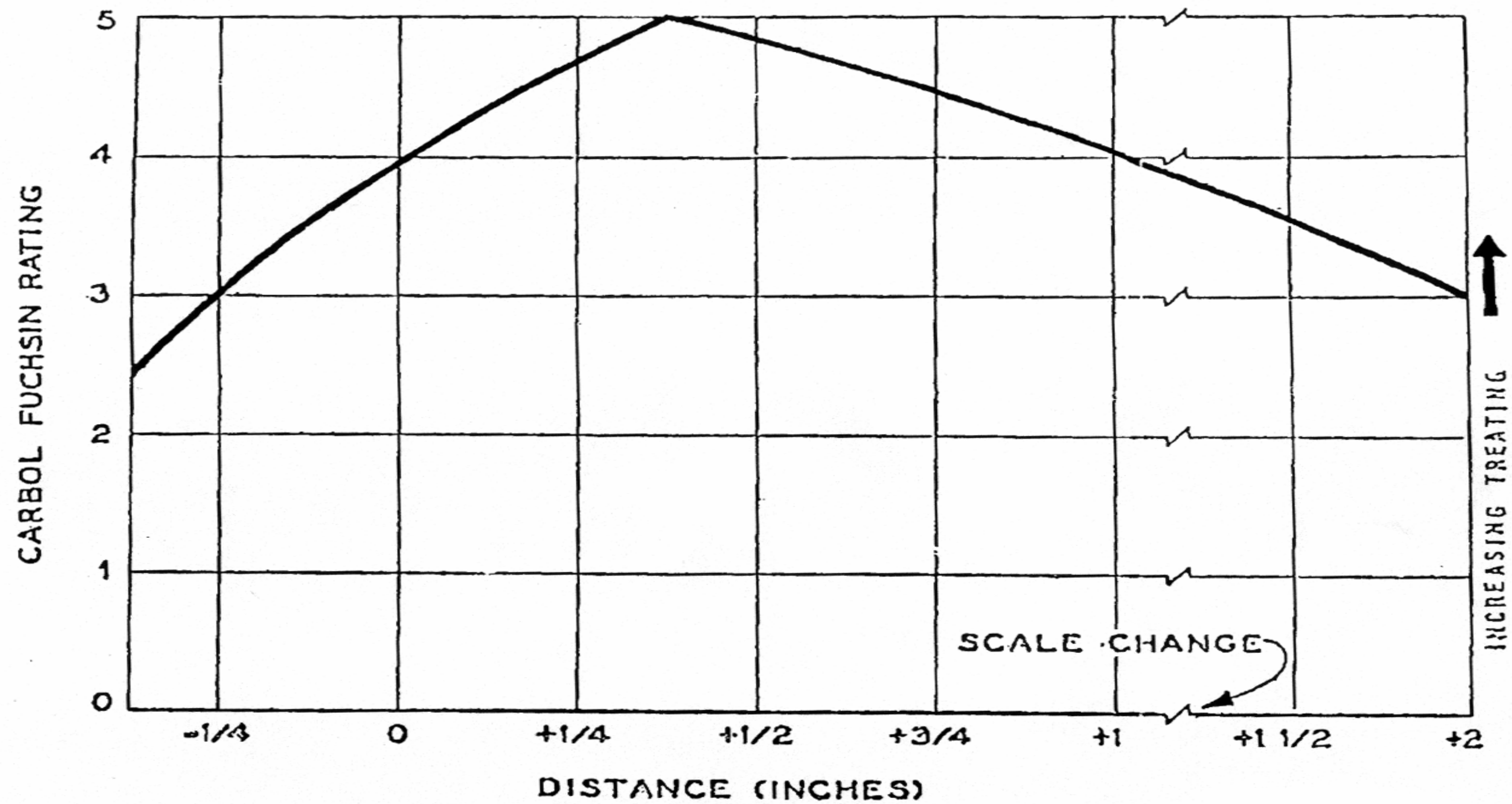
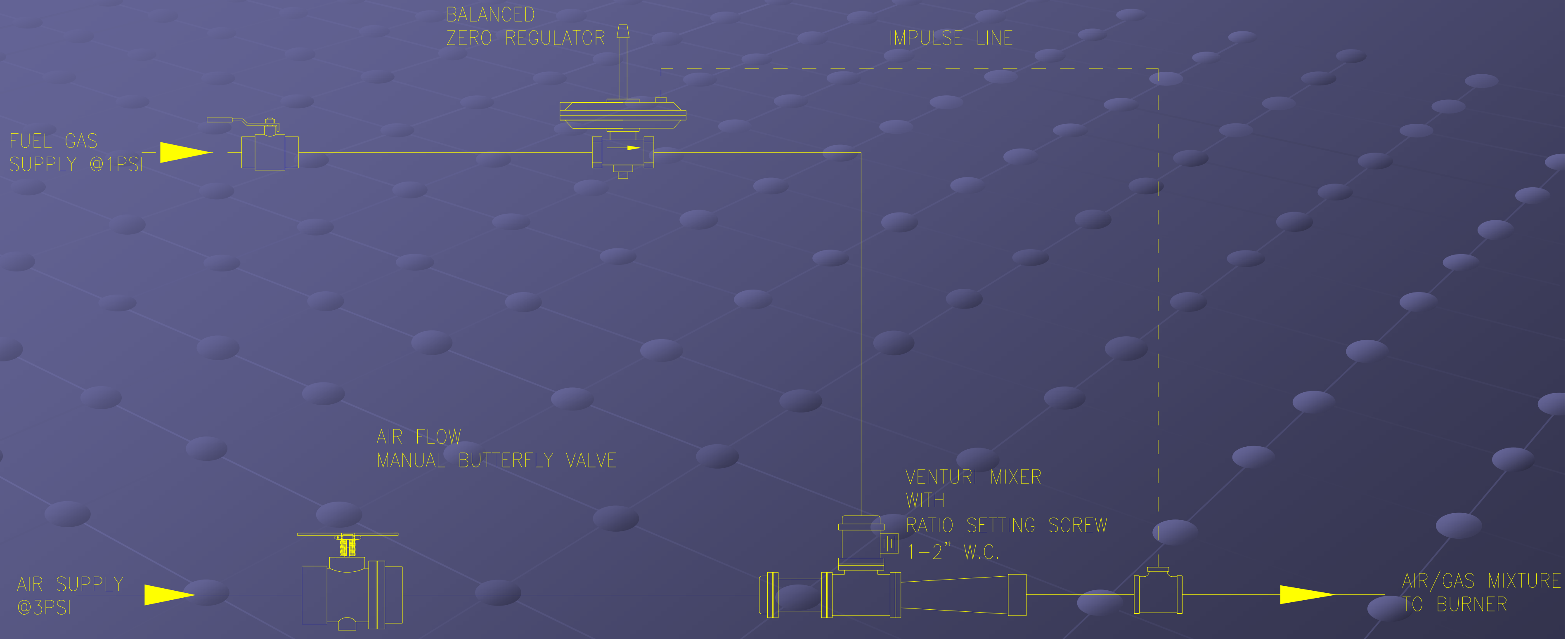


FIGURE 2

EFFECT OF DISTANCE FROM PART
TO INNER CONES OF FLAME

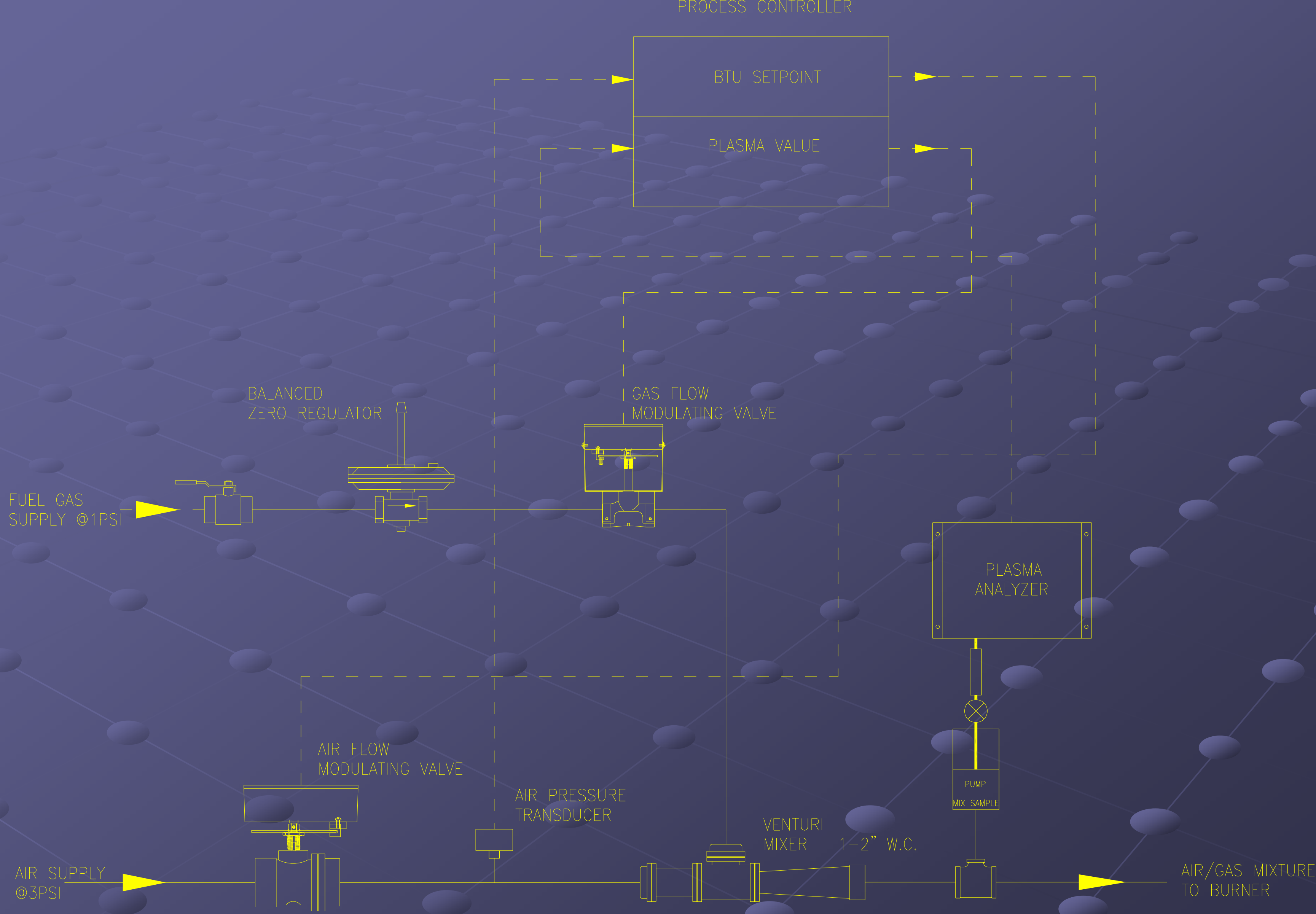
10.37 AIR/GAS RATIO
.02 SEC. CONTACT TIME
FUEL – METHANE

Control System
Zero Gas Pressure Regulator w/ Manual Air Control



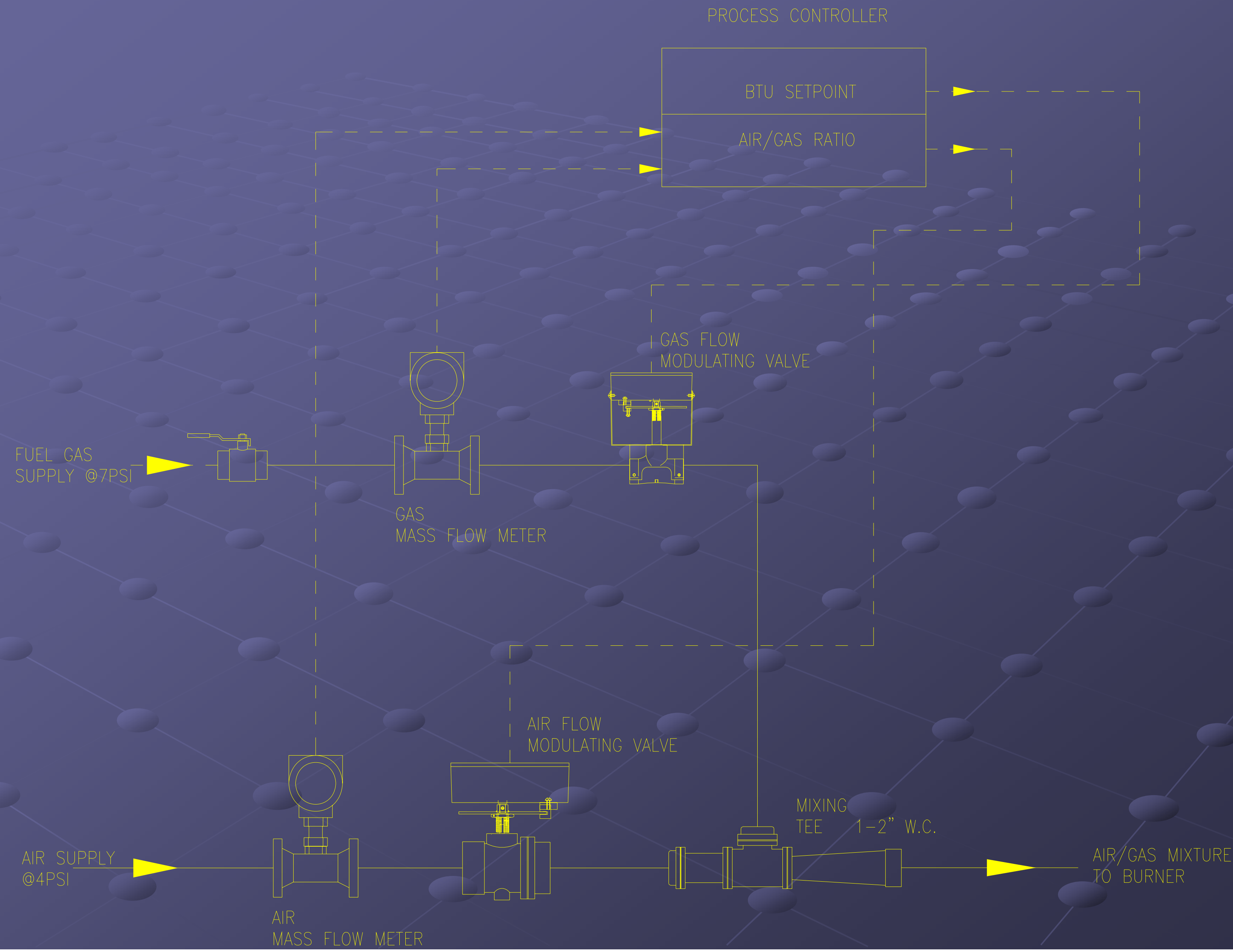
Control System

ZERO REGULATOR WITH PLASMA ANALYSIS



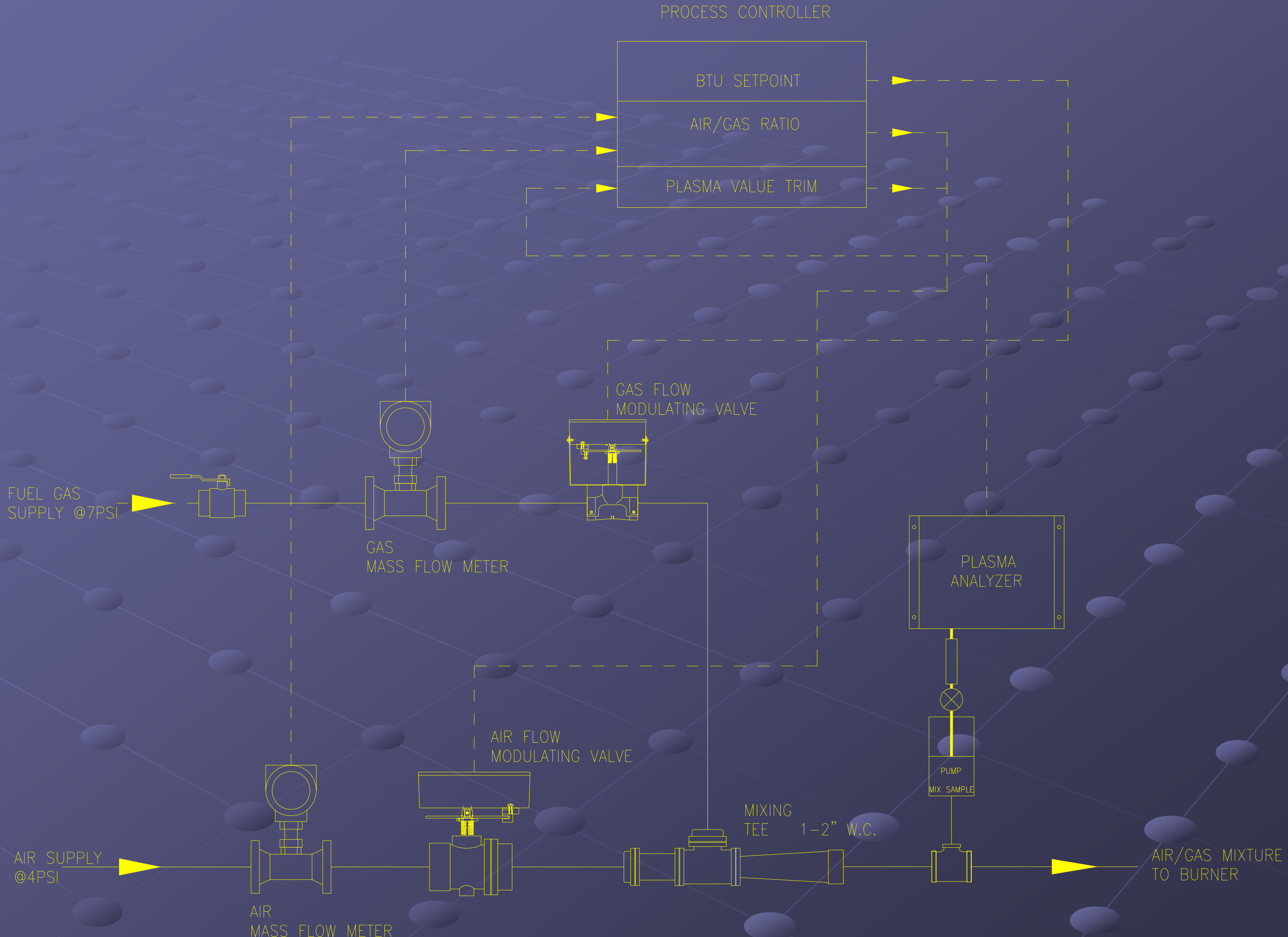
Control System

Mass Flow Control

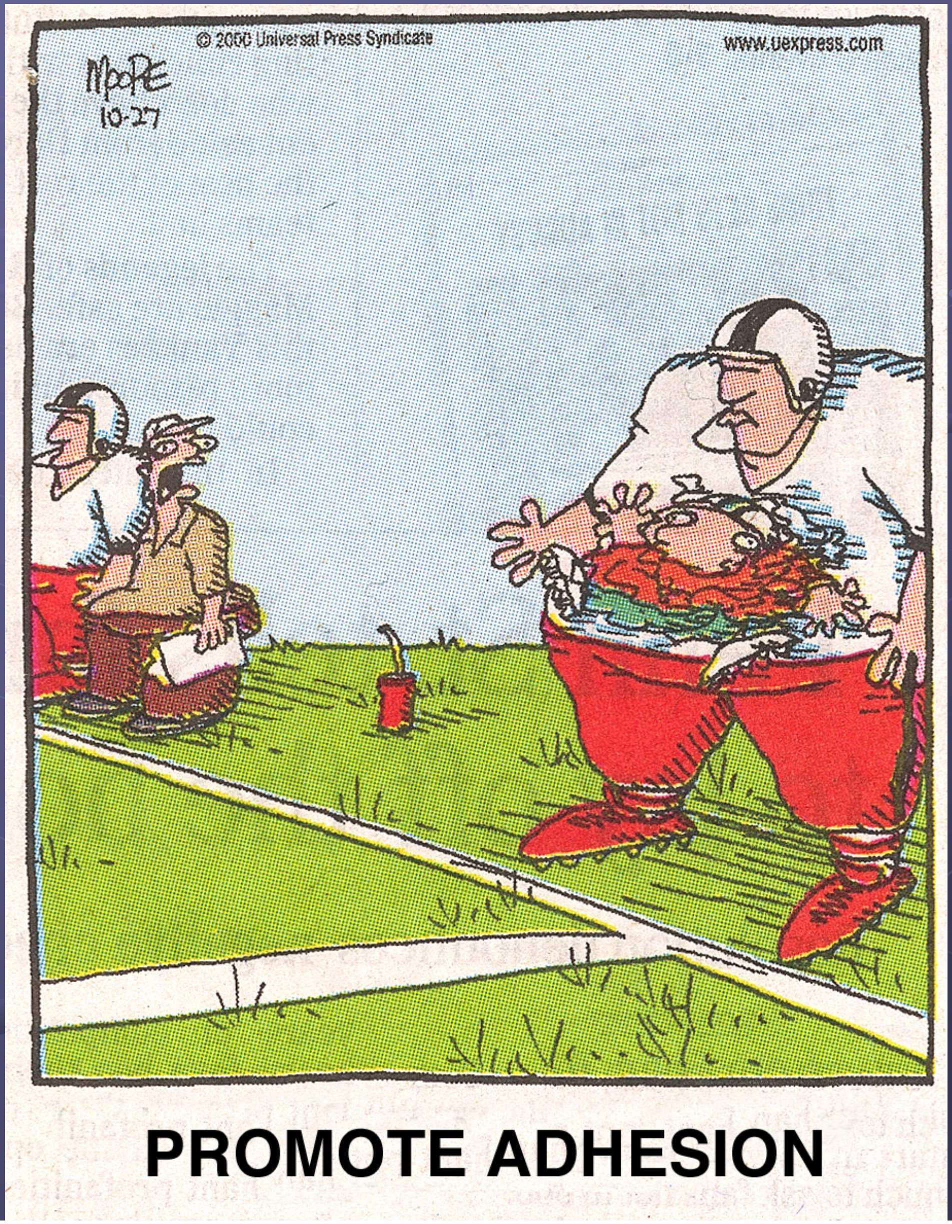


Control System

Mass FLOW CONTROL with PLASMA TRIM



Flame Treatment-it's about…..



Considerations for a Flame Treater

- Control of flame chemistry
- Burner selection
- Distance
- Control philosophy

Thank You

PRESENTED BY

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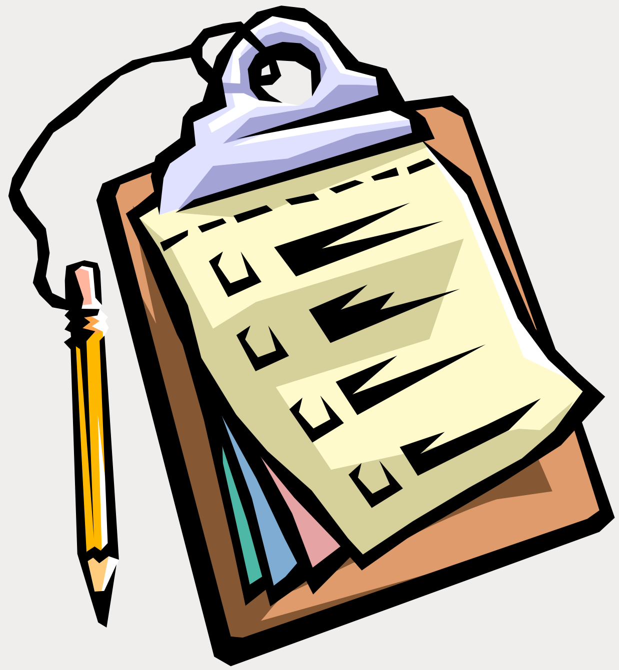

Please remember to turn in your evaluation sheet...