HIGH PRESSURE MULTI FUEL FIRED BOILERS FOR CO-GENERATION

BY

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Abstract

AN EVER widening gap between power generation and its growing demand, as well as the problems concerning the steady decline of non renewable energy resources, has been a major cause of worry, not just for India but for many countries around the world. Depletion of fossil fuels, environmental concerns and the opportunities presented for carbon trading between developed and developing countries under the Kyoto Protocol have added to the importance of Green Power. The cane sugar factories, which have been generating power only for captive use by burning bagasse during the crushing season, have taken this as an opportunity to strengthen their revenue stream by producing power on a year round basis and trading in carbon credits. This has been achieved by adopting more efficient power cycles using high pressure and high temperature boilers along with high pressure feed water heaters and extraction cum condensing steam turbines. This paper reviews the advantages of using high pressure co-generation boilers in the sugar industries with higher power output, improved cycle heat rate and lower bagasse consumption. The multi-fuel firing capacity in the boilers enables the power plant to operate on alternative fuels during the off-season when the bagasse is fully consumed. The high pressure co-generation boilers thus ensure year round operation with high availability. The paper also discusses the unique features of high pressure boilers for ensuring high uptime, enhanced life, ease of operation and maintenance, high efficiency, low power consumption and environment friendliness. Salient performance data of one of the operating high pressure boilers is also highlighted in Table 4.

Introduction

Traditionally, sugar mills have been using low pressure boilers (32 kg/cm^{2}a, 45 kg/cm^{2}a) for generating power and steam for process. In order to make the plant cycles more efficient, the trend in the sugar industries worldwide is gradually moving towards higher pressure and temperature cycles along with multi-fuel firing capability in the boilers in order to maximise generation of power from the available bagasse. This results in increased power generation during the crushing season with savings in bagasse, hence keeping the power plant operational beyond the crushing season. The plant operates on alternative fuel during the rest of the period, when bagasse is fully consumed.

The advantages of using high pressure boilers for co-generation can be seen in Table 1. With high pressure and temperature cycles, the benefits are as follows:

1. Higher power generation per tonne of bagasse.
2. Higher cycle efficiency of plant.

It is also clear from this table that keeping the pressure constant and increasing the steam temperature is not advantageous due to higher fuel consumption and drop in steam/fuel ratio.

Table 1—Advantages of a high pressure boiler.

Parameters	Unit	45 kg/cm^2(a)		66 kg/cm^2 (a)		87 kg/cm^2 (a)		105 kg/cm^2 (a)/540^{0}C
		440^{0}C	515^{0}C	485^{0}C	515^{0}C	515^{0}C	540^{0}C	
Feed water temp. to boiler	^{0}C	105(without HP heater)		150(with 1 HP heater)		170 (with 1 HP heater)		220 (with 2 HP heaters)
Bagasse quantity	TPH	43.51	46.18	41.78	42.89	41.2	42.2	38.6
Steam/fuel ratio	–	2.29	2.16	2.39	2.33	2.42	2.36	2.59
Gross power output	MW	24.8	28.8	26.5	28.9	28.5	29.4	29.4
Net power output	MW	22	25.2	23.4	25.3	25.1	25.7	25.9
Specific steam consumption	kg/kW–h	4.03	3.46	3.77	3.46	3.51	3.40	3.40
Power generation per ton of bagasse	kW/Tonne	Base	+9.5%	+ 11.4%	+18.3%	+ 21.4%	+ 22.3%	+ 33%
Heat rate	kcals/kW–h	3983	3640	3579	3370	3281	3258	2980

Development of high pressure co-generation boilers

High pressure and high temperature cycles are important for increasing the operating efficiency and power output from co-generation plants. The choice of pressure and temperature levels for the steam cycle depends on several factors including fuel and ash properties, quality of feed water and water treatment systems available, cost of boiler and steam turbine systems and the level of confidence of plant operators.

Thermodynamically, the energy recovery from the Rankine cycle depends more on steam temperature than pressure. The cycle efficiency will increase with higher steam temperature. However, because of the nature of the working medium, pressure also plays a major role in ensuring optimum extraction of useful energy from the working medium as the enthalpy changes with pressure. Hence, an increase in steam temperature should be accompanied by a matching increase in steam pressure. The temperature selection is decided by the metallurgy of boiler pressure parts, piping, turbine components and the creep-fatigue behaviour of materials at higher temperature. For temperatures up to 400°C, carbon steel material (SA 210 Gr A1/SA 210 GrC) is used for the heating surfaces. Alloy steel material (SA 213 T11, SA 213 T22) is used for temperature up to 520°C. For higher temperature (540/545ºC), special alloy steel material (SA 213 T91) is used for the heating surfaces.

Having gained wide experience with operation of 66 kg/cm^2(a), 485ºC cycle, the Indian sugar industry graduated to the next higher cycle using 87 kg/cm^2(a), 515ºC cycle. Several co-generation boilers using this pressure cycle are successfully operating in India. The current trend is for still higher pressure operation at 105/110 kg/cm^2(a) and 540ºC. Three units using this pressure cycle have been in operation for the past two years. Many more units using 110 kg/cm^2(a) pressure are currently under execution.

The concept of regenerative feed water heating was introduced in the co-generation cycles to improve cycle efficiency. High pressure feed water heaters using bleed steam from the turbine have become a standard feature in all co-generation plants. The 66/87 kg/cm^2(a) cycle uses one high pressure feed water heater to increase the feed water temperature to around 170ºC before entering the economiser. The 105/110 kg/cm^2(a) cycle uses two stages of high pressure heaters to raise the feed water temperature to around 220ºC before entering the economiser. Regenerative feed water heating reduces the heat input to the boiler, thus optimising fuel consumption and increasing steam/fuel ratio.

The significant advantages of using a high pressure boiler in co-generation are:

- Saving in bagasse, hence extended period of operation.
- Higher power generation per tonne of bagasse.
- Lower fuel and steam consumption for the same power output, hence reduced boiler size.
- Improved heat rate, hence better cycle efficiency of the plant.

While efforts are being made to increase power generation by adopting higher pressure cycles, energy conservation efforts are also being introduced for optimising auxiliary power consumption and increasing the exportable surplus power to the grid.

Variable frequency drives are being extensively used to bring down the auxiliary power consumption. Boilers are designed with multi-fuel firing capability so as to ensure year round operation of the plant.

One of the major considerations for high pressure operation is the quality of feed water, boiler water and steam. Total solids and silica are required to be maintained at low levels in drum water at high pressures to maintain desired steam quality. Silica, in particular, is carried over in the form of vapour at high pressures and, hence, the silica content in feed water needs to be maintained at a very low level. Feed water is used for attemperation in the superheater system and any contamination in the feed water will enter the superheater circuit. This necessitates high purity for make-up water. Hence demineralisation and volatile treatments become necessary and the boiler water quality control becomes critical to minimise steam impurities to prevent deposits in tubes and turbine blades. Demineralisation can produce the acceptable make-up water quality with specific electrical conductivity less than 0.5 µs/cm with hardness completely removed and silica less than 0.02 ppm. Demineralisation of boiler feed water prevents failures due to deposits, ductile gouging, hydrogen embrittlement and corrosion.

The recommended feed water and boiler water quality is shown in Table 2 and Table 3 respectively. Salient performance data of one of the operating high pressure boilers is also highlighted in Table 4.

Table 2—Recommended feed water quality.

Parameters	Unit	45 kg/cm^2(a)	66 kg/cm^2(a)	87 kg/cm^2(a)	105 kg/cm^2(a)
pH		8.8–9.2	8.8–9.2	8.8–9.2	8.8–9.2
Hardness	ppm	Nil	Nil	Nil	Nil
Specific electrical conductivity after cation exchanger	µs/cm	2.0	0.5	0.5	0.3
Dissolved oxygen	ppm	0.20	0.007	0.007	0.005
Total dissolved solids	ppm	1.0	0.25	0.25	0.15
Silica	ppm	1.0	0.02	0.02	0.02
Total iron	ppm	0.05	0.01	0.01	0.005
Total copper	ppm	0.01	0.01	0.01	0.005

Table 3—Recommended boiler water quality.

Parameters	Unit	45 kg/cm^2(a)	66 kg/cm^2(a)	87 kg/cm^2(a)	105 kg/cm^2(a)
pH		9.8–10.2	9.0–10.0	9.0–10.0	9.0–10.0
Total dissolved solids	ppm	150	100	100	100
Specific electrical conductivity	µs/cm	300	200	200	200
Silica	ppm	10	5 *	2.5 *	1.5 *
Residual phosphate	ppm	15–25	5–20	5–20	5–20

* To be controlled based on drum operating pressure so as to maintain silica less than 0.02 ppm in the steam leaving the boiler drum.

Table 4—Boiler performance.

Parameters	Unit	87 kg/cm^2(a), 515ºc		105 kg/cm^2(a), 540ºc	
		Designed values	Achieved values	Designed values	Achieved values
Plant		Nizam Deccan Sugars, India		Dhampur Sugars, India	
Steam flow at main steam stop valve	tph	110	110	170	171.4
Steam temperature at main steam stop valve	Deg.C	515 ± 5	515	540 ± 5	540
Steam pressure at main steam stop valve	kg/cm^2(a)	87	87.2	105	105.4
Feed water temperature at economiser inlet	Deg.C	170	168	220	218
Back end temperature	Deg.C	150	148	150	146
Boiler efficiency on GCV basis	%	71.5	72.7	71.7	71.4
Auxiliary power consumption	kW	1096	1025	1912	1754
Particulate emission at ESP outlet	mg/Nm^3	115	115	150	150
Noise level of rotating equipment at one metre distance	dB	85	< 85	85	< 85

Features of high pressure boilers

For developing a boiler for cogeneration and suitable for generating power on a sustainable basis the following points are important:

1. Need for multi fuel firing.
2. Ability to give trouble free service throughout the year.

Of the several technologies available, the Travelling Grate boiler can burn bagasse as well as a variety of biomass fuels and agro wastes including rice husk, wood chips, and cotton stalk, besides fossil fuels like coal, lignite, oil and gas during the off season. Examples are shown in Figures 1, 2 and 3.

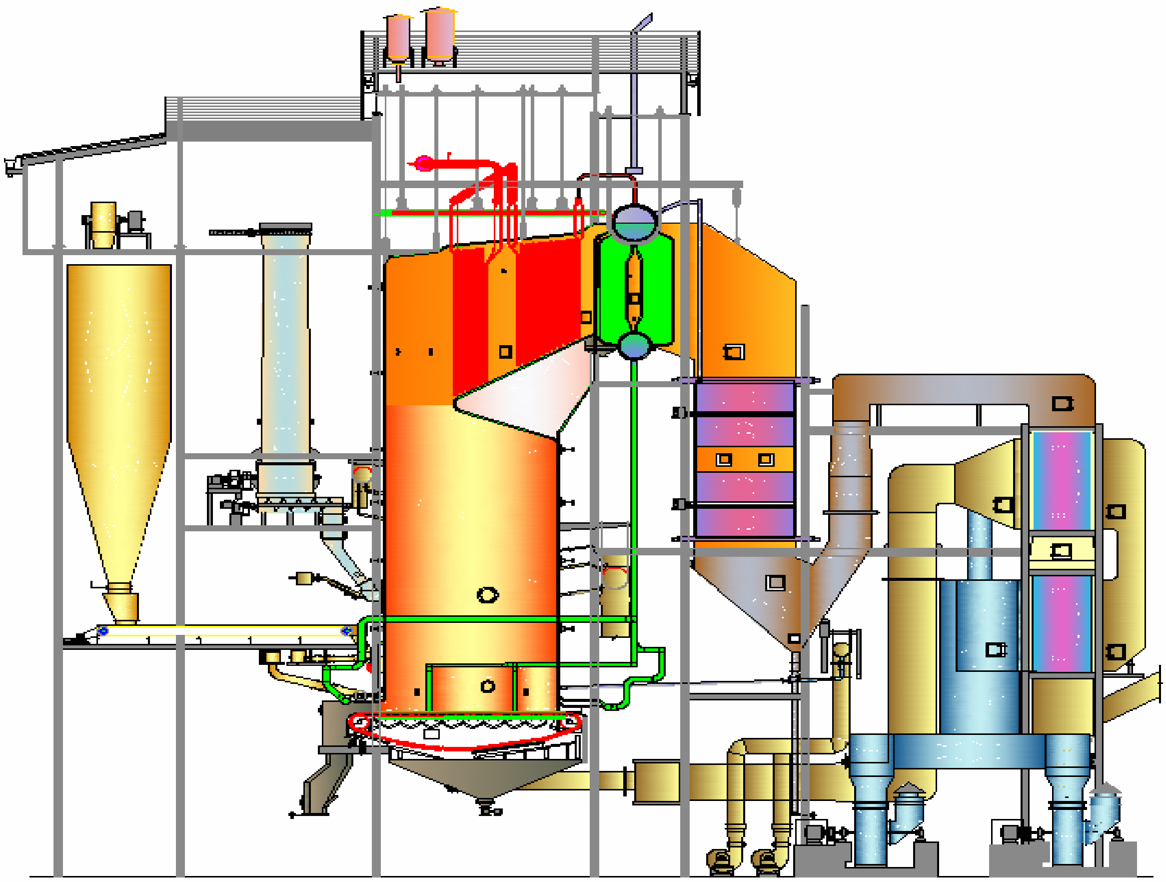

Fig. 1—Travelling grate boiler with boiler bank. Source: ISGEC John Thompson.

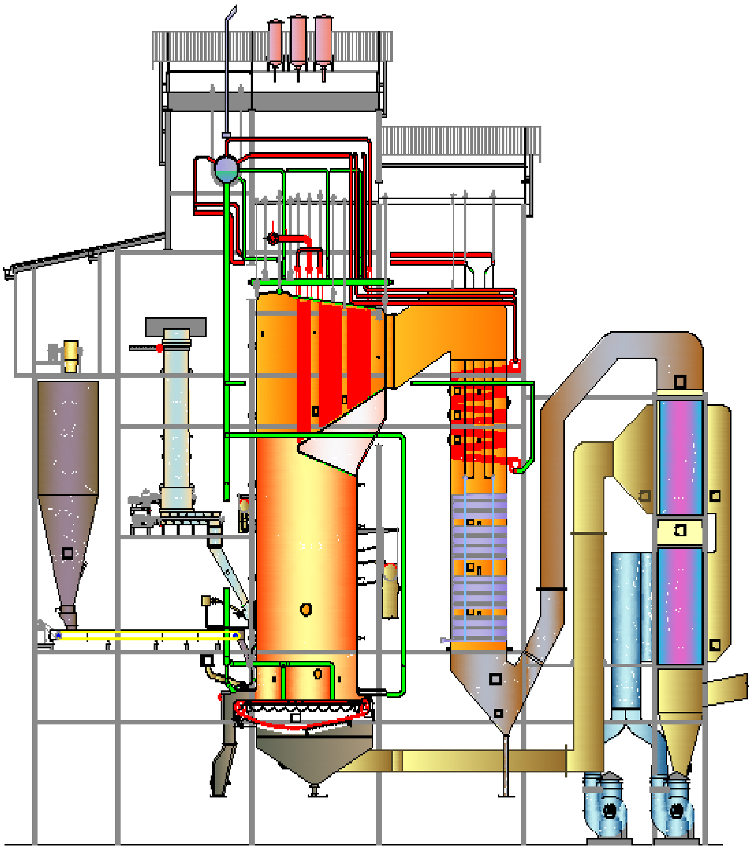

Fig. 2—Single drum design travelling grate boiler with evaporator pass.

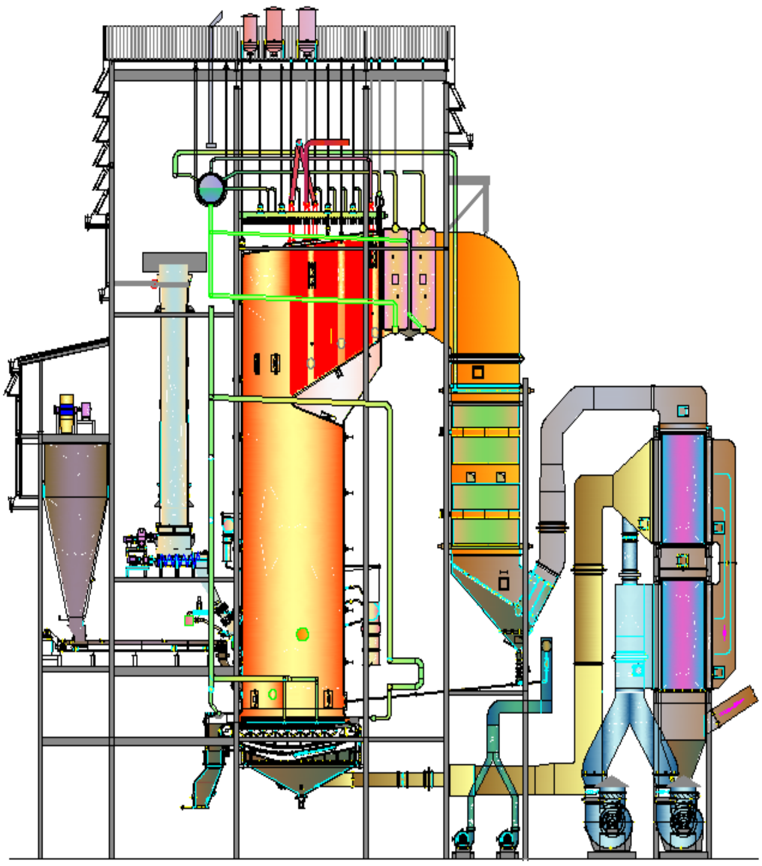

Fig. 3—Single drum design travelling grate boiler with evaporator bank.

For robust and reliable operation on a year round basis, the high pressure co-generation Travelling Grate boiler needs to have the following essential features.

- High uptime
- High efficiency
- Low power consumption
- Environment friendly
- Low O & M cost

The specific design and construction features that IJT has incorporated in their Travelling Grate boilers are:

High boiler uptime

1. Stoker of rugged construction using heat resistant grate bars of Spheroidal Graphite iron metallurgy and chains made of hardened and tempered steel, cross beams and skid bars made of heavy sections and heat resistant material.
2. Pressure part tubes of seamless construction
3. Single pass in-line boiler bank tubes to eliminate eddies and hence erosion.
4. Optimum flue gas velocities across heating surfaces to minimise erosion.
5. Furnace made of water cooled membrane wall construction to ensure gas tightness and minimum use of refractory to avoid maintenance.
6. Use of SA 213 T91 material for final elements of secondary superheater for high creep, fatigue and corrosion resistance.
7. Convective superheaters with wide pitching to avoid fouling due to alkali content in ash.
8. Double casing arrangement for economiser to protect bends from erosion.
9. Use of corten steel tubes in cold end section of tubular airheater to avoid corrosion.
10. Use of ferrules for airheater inlet tubes to avoid erosion.
11. Use of pre-dust collector at economiser outlet to reduce particulate loading on ESP; this avoids larger unburnt carbon carry over to ESP and hence eliminates fire hazards.
12. Stoker shaft provided with self lubricated graphite bearings ensures high reliability, minimum maintenance.
13. Refractory band provided at lower furnace zone above the grate to sustain combustion even with high moisture in bagasse.
14. Single drum design for high pressure (> 100 kg/cm^{2}a) boilers. High ligament efficiency of drum (85–90%), lower drum thickness, no tube expansion and better circulation due to non-heated downcomers.
15. Tall furnace, generous volumetric loading ensures adequate residence time for fuel, hence reduces unburnt carbon loss.
16. On-line vibration monitoring system provided for critical rotating equipment ensures predictive maintenance and avoids failures.
17. On-line steam and water analyser system ensures strict control of water chemistry.
18. Automated operation with Distributed Control System with supervisory controls and data acquisition for accurate control with less manpower.

High efficiency

a) Generous sizing of furnace (conservative grate area and furnace volumetric loading) for efficient combustion of fuel.

b) Good secondary air distribution using high pressure air jets to ensure better turbulence and mixing due to staggered arrangement for efficient combustion of fuel.

c) Heat recovery through economiser and airheater for lower back and temperature.

d) Optimum excess air levels to reduce dry flue gas loss.

e) Refiring of grit and cinder for lower unburnt carbon loss.

f) Use of high pressure feed water heaters for fuel economy.

g) Use of variable frequency drive for feeders to regulate fuel feed.

Low power consumption

a) Use of low flue gas velocity across heating surfaces to reduce draft loss in gas path.

b) Use of variable frequency drives for fans and boiler feed pumps.

Environment friendly

a) Use of Electrostatic Precipitators to limit particulate emission to 30–50 mg/Nm^3. Electrostatic Precipitators also have low flue draft loss (25–30 mm WC).

b) Use of closed dense phase system for fly ash disposal.

c) Use of efficient silencers to meet occupational Health and Safety Administration (OSHA) norms.

Low O & M cost

a) Automated operation, hence less manpower.

b) On line monitoring of condensate and boiler feed water quality using Steam and Water Analyser System (SWAS) prevents scaling and corrosion in boiler tubes, hence avoiding tube failures and ensuring high boiler availability.

c) Seamless steel tubes for boiler pressure parts, eliminates tube leakages, ensures high boiler availability with minimum maintenance.

d) Alloy steel tubes for superheaters, corten steel material for cold end of airheater provides resistance to corrosion, fatigue and ensures high boiler availability.

e) Replaceable wear liners for ID fan blades ensures resistance to erosion.

f) Use of soot blowers at strategic location for efficient on-load cleaning of heating surfaces hence avoiding fouling and bridging of ash particles in the heating surfaces.

g) Use of air bypass arrangement for the air preheater to avoid cold end corrosion during boiler start up, part load operation and also during low ambient air temperature conditions to ensure high boiler availability.

Specific design and construction features of high pressure boilers

- Rotary single drum feeder/Three drum feeder/Chain feeder for bagasse with pneumatic spreaders.
- Drag chain feeder for coal with mechanical/pneumatic spreaders.
- Three stage feed water heating (deaerator and two stages of HP heaters).
- Spray-cum-Tray type deaerator to achieve low dissolved oxygen (< 0.007 ppm) in boiler feed water.
- Convective superheater arrangement (shielded by nose) with interstage attemperator).
- Use of drum coil heaters for minimising cold end corrosion in economiser due to sulfur in fuel.
- Use of steam coil air preheater for minimising cold end corrosion in air heater during very low ambient air temperature.
- Conservatively designed steam drum to enable boiler operation with rapid load swings and fast response to load changes.

- Efficient drum internals consisting of cyclone separators, demisters to ensure high steam purity at all loads.
- Self lubricated graphite bearings (Morganite bearings) provided for stoker shaft. The morganite carbon bearing is chemically inert, dimensionally stable, non hygroscopic and highly resistant to wear.
- Drum internals of bolted construction for easy replacement/removal
- Temperature elements are provided on the Travelling Grate skid bar, cross beam and riddling hoppers with temperature indication in the control room.
- Minimum use of refractory in the boiler, thereby eliminating cumbersome maintenance.

Conclusion

With the rapid industrial growth over the last few decades, the demand for electrical energy has been growing at a tremendous pace. The application of the clean development mechanism (CDM) of the Kyoto protocol which gives monetary value to CO_2 emission reduction has become an important financial driver for biomass based co-generation.

Due to concerns related to cost and to bring about a reduction in emission of air pollutants and greenhouse gases, owners of industrial and commercial facilities are actively looking for ways to produce energy more efficiently. The incentive of trading carbon credits has become a motivation for considering the co-generation route. India has no doubt emerged as one of the leaders in co-generation.

The sugar industry in India has made phenomenal progress in co-generation particularly since bagasse, a waste product from sugar mills, is available at almost no cost as fuel. However, as bagasse is a seasonal fuel, there is a need to find other biomass fuels for year round generation of power. This has led to the development of multi-fuel fired boilers using high pressure and high temperature cycles which are crucial for increasing operating efficiency and power output from co-generation plants.

The additional power generation is a source of revenue for the sugar plant with opportunities to generate more income through trading of carbon credits.

CHAUDIERES A HAUTE PRESSION ET A MULTIPLE COMBUSTIBLES POUR LA COGÉNÉRATION

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MOTS-CLÉS: Chaudières Bagasses De Cannes à Sucre à Haute Pression, Cycles Themodynamic Efficace, Importantes Caractéristiques Mécaniques.

Résumé

UN FOSSÉ toujours grandissant entre la production d'électricité et de sa demande croissante, ainsi que les problèmes relatifs à la diminution constante des ressources énergétiques non renouvelables, a été une des causes d'inquiétude majeure, non seulement pour l'Inde, mais aussi pour de nombreux pays à travers le monde. L'épuisement des combustibles fossiles, les préoccupations environnementales et les opportunités présentées pour les échanges de carbone entre pays développés et ce en voie de développement dans le cadre du protocole de Kyoto ont donné davantage d'importance à l'énergie verte. Les usines de canne à sucre, qui ont été génératrices de puissance uniquement pour leur usage interne par combustion de bagasse de canne pendant la saison de broyage, ont saisi cette opportunité pour augmenter leurs revenus en produisant de l'énergie toute l'année et à travers la négociation des crédits de carbone. Cet objectif a été atteint par l'adoption des cycles d'alimentation plus efficaces à l'aide de chaudières à haute pression et à haute température associées à des systèmes d'alimentation d'eau à forte pression et des turbines à vapeur d'extraction cum condensation. Cette communication présente les avantages de l'utilisation de chaudières de cogénération de haute pression dans les industries sucrières avec une augmentation de puissance générée, une amélioration du taux de transfer de chaleur et une diminution dans la consommation de bagasse de canne. La capacité des chaudières à utiliser differents types de combustibles pendant la periode d'inter-récolte quand la bagasse n'est plus disponible, permet à la centrale électrique de fonctionner pendant toute l'année. Les chaudières de cogénération à haute pression assurent ainsi le fonctionnement pendant toute l'année avec un haut degrè de disponibilité. La communication comprend également des fonctionnalités uniques des chaudières à haute pression pour assurer une meilleure disponibilité, une durée de vie accrue, une facilité d'opération et d'entretien, une meilleure efficacité, une faible consommation et le respect de l'environnement. Les données saillantes de la performance d'une chaudière à haute pression en phase d'opération sont également mises en évidence au tableau 4.

CALDERAS DE ALTA PRESIÓN MULTICOMBUSTIBLES PARA LA COGENERACIÓN

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**PALABRAS CLAVE: Calderas de Bagazo de Alta Presión,
Ciclos Termodinámicos Eficientes, Factores Mecánicos Importantes.**

Resumen

UNA BRECHA permanentemente creciente entre la generación de energía y la ampliación de su demanda, así como el problema relativo al sostenido decrecimiento de las fuentes de energía no-renovables, ha resultado causa de la mayor preocupación no solo para la India sino también para muchos países del mundo. Depresión de los combustibles fósiles, alarma ambiental y las oportunidades que presentó el comercio de carbono entre los países desarrollados y en desarrollo bajo el Protocolo de Kyoto, han contribuido a añadir importancia a la Energía Verde. Las fábricas de azúcar de caña que han generado energía solamente para un uso cautivo por la combustión del bagazo durante el período de producción azucarera, han tomado esto como una oportunidad para fortalecer corrientes de ingresos por la vía de producir energía todo el año y negociando en créditos de carbono. Esto se ha alcanzado adoptando ciclos energéticos más eficientes, empleando calderas de alta presión y temperatura, junto a calentadores de alta presión de alimentación y turbinas de extracción-condensación. Este artículo revisa las ventajas de emplear calderas de alta presión para cogeneración en la industria azucarera con mayores producciones de energía, ciclos con relaciones de calor mejorados y menores consumos de bagazo. La capacidad de las calderas de quemar varios combustibles permiten a las plantas de energía operar en el período de no producción azucarera con combustibles alternativos una vez consumido todo el bagazo. Las calderas de alta presión para cogeneración aseguran, así, una operación todo el año con alta disponibilidad. El artículo discute también, la propiedad única de las calderas de alta presión para asegurar elevada operacionalidad, larga vida útil, facilidad de operación y mantenimiento, alta eficiencia, bajo consumo energético y ser eco-amigables. En la tabla 4, se destacan las cifras de desempeño de una caldera de alta presión en operación.