Fuel Substitution for Energy Saving

A Case Study of Foundry Plant

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Abstract—**Foundry based organizations consume significant amounts of energy for producing their final products. Recently, techno-commercial and environmental factors have started triggering change from fossil fuels to cleaner ones. In this paper, factors acting as driving forces for migration from one fuel to another in order to improve energy efficiency, including various performance parameters in support of environment preservation, have been identified. Focus is also given to challenges which encounter during fuel switching. A new framework has been applied that can be used for fuel switching in manufacturing organizations. A real case of switching from three types of fuels to a single fuel has been studied and the outcomes are evaluated. Analysis related to energy consumption before and after fuel switching with respect to corresponding production data have been performed.**

Keywords-foundry industry; natural gas; energy consumption; energy efficiency; fuel switching; public sector organization; calorific values; fund saving; castings; liquid fuels

I. INTRODUCTION

Foundry [1] is one of the most energy-intensive industry sectors due to its energy-oriented manufacturing processes. India holds a significant share of foundries worldwide. There are around 47,000 casting units globally, out of which approximately 4,500 units are in India. According to [2], world casting production was 104.1 million metric tons in 2015. The share of China alone was reported to be 44% whereas India and USA together hold 20% of global casting production. Major foundry clusters of India are located at Batala, Jalandhar, Ludhiana, Agra, Pune, Kolhapur, Sholapur, Rajkot, Mumbai, Ahmedabad, Belgaum, Coimbatore, Chennai, Hyderabad, Howrah, Kolkata, Indore, Chennai, Faridabad, Gurgaon etc. [3]. A huge amount of energy is consumed in foundry plants, thus requiring maximization of energy efficiency, i.e. using less energy for performing a desired task or service [4]. In India, BEE (Bureau of Energy Efficiency) [5], a statutory body formed by the government of India issues energy efficiency measures in industrial fields. In casting process, melting of a material is the most energy intensive process, thus, the need of having energy efficient casting processes emerges [6]. Recently the focus of foundries is shifting towards coke less furnaces, in particular, induction furnaces [7]. Organizations are using various types of fuels like furnace oil, light diesel oil (LDO), high-speed diesel (HSD), liquefied petroleum gas (LPG) and natural gas (NG) in furnaces for carrying out heat treatment procedures. Selection and switching of appropriate fuel is an essential decision for improving energy efficiency and fuel economy. Energy audit is one of the effective tools suggested to industries in order to identify and improve energy performance [8]. This paper provides identification of potential measures for energy efficiency through fuel switching. In this paper a framework has been proposed that identifies the impact of utilization of various fuels for foundry industries.

A. Importance of Fuel Switching in Foundry Industry

This industry, being energy intensive, has a huge potential for improving energy efficiency. Improving energy performance of an enterprise will directly reduce energy costs and improve profitability. Consideration of an efficient fuel over existing ones is a vital aspect and will help in achieving energy efficiency with a great impact.

B. Motivation

Global warming is taking place because of the uncontrolled use of energy sources. Carbon emissions are an important factor adversely affecting the environment. There is a strong need worldwide to reduce carbon emissions and improve energy efficiency. Improvement of energy performance not only leads to saving of natural reserves, but also serves the purpose of reducing carbon emissions. The fact that energy efficiency has a broader sense in terms of global warming and environment, motivates towards the use of environmental friendly fuels and for improvement in energy efficiency through fuel switching.

C. Our Contribution

This paper analyzes the demand of fuel switching in casting industries if they are not working with energy efficient fuels. In this paper a new framework for fuel switching has been established. The framework will help the casting manufacturing enterprises to recognize the performance of existing fuel as well as the opportunities for improving energy performance through fuel switching to an efficient and clean fuel. The contribution of energy efficiency exclusively from fuel switching has been studied. The framework is validated through the case study of a Maharatna public sector Company of India, CFFP, BHEL Haridwar.

II. RELATED WORK

Related work is divided into two parts. The first part is concerned with energy efficiency measures in the foundry field and the second part includes various studies of fuel switching in different domains.

A. Energy Efficiency Measures in the Foundry Field

In [9], authors suggested the use of cleaner technologies in foundry based industry. In [10], authors dealt with the reduction of hazardous waste (HW) in several industries. A study of developing countries for providing resource efficient gains is shown in [11]. In [12], highlighted limitations for Sri Lanka for cleaner technologies in foundry industries were researched. Author in [13] elaborated energy efficiency practices and energy-efficient technologies for iron and steel plants. Authors in [14] suggested the reduction in specific energy use irrespective of payback period in iron and steel industry for 2020 over 2010. Energy efficiency scenarios are shown in [15] for economic energy saving opportunities of iron and steel industry of India for the duration from 2010 to 2030. Authors in [16] outlined a case study of the existing melting techniques in a steel foundry. Authors in [17] focused on the measures for improving energy efficiency in an aluminum foundry.

B. Fuel Switching in Different Domains

Fuel switching replaces inefficient fuels with cleaner and economical alternatives. The work in [18] is a part of a wider study to measure resource depletion using its environmental and economic impacts for the case of natural gas. In [19] large emission reductions were seen for conversions from oil and gas boilers to a biomass based system. Authors in [20] showed that the main policy is to reduce the demand for firewood and to mitigate environmental degradation. Authors in [21] show a comparative model of four options, namely biogas, solar energy, heat pump and imported heat.

C. Research Gap and Problem Identification

In foundry sector the research work done is mainly about the improvement in energy efficiency of melting processes, whether it is scrap charging, use of insulation material, control of temperature or other operational improvements. At the best of our knowledge there is a lack in the available literature regarding energy efficiency improvements in foundry with the help of fuel switching. It is evident that fuel switching is an important aspect of energy saving. This paper provides a unique framework for fuel switching in organizations especially for foundry industries to improve their energy performance.

III. FRAMEWORK FOR FUEL SWITCHING IN FOUNDRIES

In this section, we present the framework developed for the switching from old existing fuel to an energy efficient fuel. The framework has five major components, shown in Figure 1.

A. Study of Reference System with Existing Fuel

In this phase, the details of the existing system in the organization have to be identified. All types of fuels under existing scenario are to be listed. The fuel consumption can also be recorded with respect to production. The energy saving opportunities for higher energy consumption processes through fuel switching are to be identified through the following processes:

- Analysis of actual energy consumption of various equipment and comparative assessment with standard similar equipment.
- Setting targets along with action plans for achieving the identified opportunities in the switching of fuel.
- Identification of environmental, legal and other obligations as applicable for existing fuel.

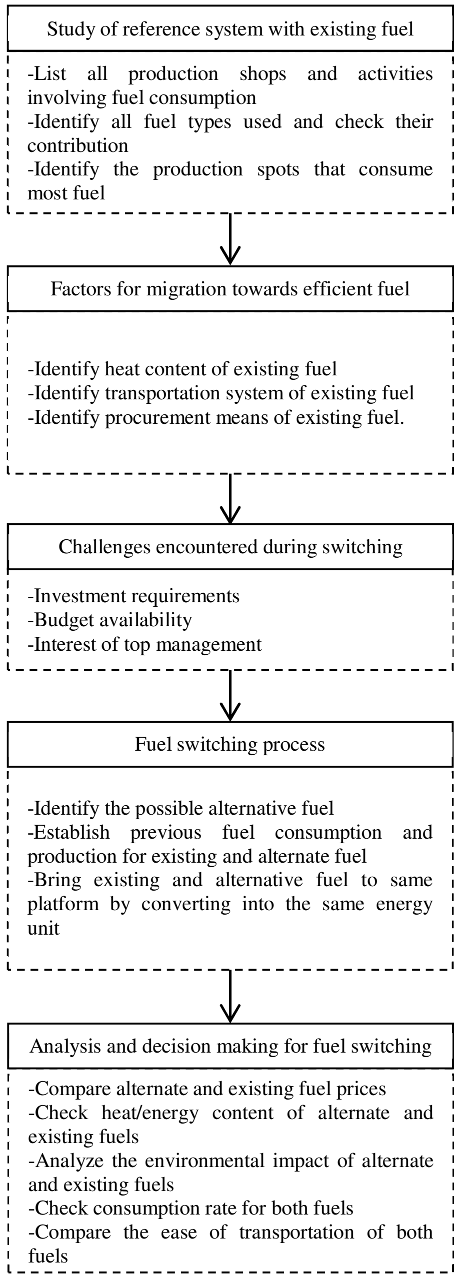

Fig. 1. Frame work for fuel switching

B. Factors for Migration Towards Efficient Fuel

This is the phase of framework that will help in decision making for switching of fuel. The activities at this stage are as below:

- Calculation of SEC (specific energy consumption) based on production data and consumed fuel data.
- Calculation of savings that may result due to reduction in energy consumption achieved from the switching.

C. Challenges Encountered During Switching.

Investments will be needed for making changes in the existing infrastructure, to make it compatible with alternate fuel. The availability of sufficient infrastructure and its management is needed in order to switch smoothly from one fuel to another, which should be ensured at this stage.

D. Fuel Switching Process

In this stage, first of all the enterprise has to explore all the possible alternate fuels available in the market that may replace the existing ones. Care should be taken while selecting alternate fuel as the selection should require minimum changes in the existing infrastructure. Fuel consumption of existing and possible alternate fuel is to be calculated.

E. Analysis and Decision Making for Fuel Switching

This phase focuses on the analysis and comparison between the existing and alternate fuel. The final decision of fuel switching can be taken based on the results. The heat content of both fuels is to be compared along with the consumption rate with respect to per unit production. The initial investment cost is to be compared with savings that will occur due to substitution of old fuel.

IV. CASE STUDY: CFFP, BHEL

This paper presents the case study of Central Foundry Forge Plant (CFFP), BHEL, Hardwar for migration of their fuels namely, LDO, HSD, and LPG to a single fuel, i.e. natural gas. We studied the manufacturing processes and the energy consumption of the CFFP. The enterprise is engaged in the manufacturing of heavy weight casting and forgings in various steel grades. In its quest to improve energy performance, CFFP has recently got certification for Energy Management System standard, ISO-50001 [22]. Along with this, it is an ISO-9001 [23], ISO-14001 [24] and OHSAS-18001 [25] certified company. Apart from producing components for various other applications, components are produced mainly in four steel grades namely, Plain Carbon Grade, Alloy Steel Grade, Stainless Steel and Supercritical Grade Steel [26].

A. Study of Reference System with Existing Fuel

In this phase, analysis on the energy consumption pattern of CFFP has taken place. Until recently, CFFP was consuming energy in various forms (LDO, HSD, LPG and electricity) for its operations. Handling and use of these fuels were proving to be inefficient and involved environmental and safety hazards. The consumption of liquid fuels and LPG in CFFP was mainly for furnaces, cutting operations, boilers and pre-heating of ladles for molten steel. The operations and interactions of these sectors are represented in Figure 2.

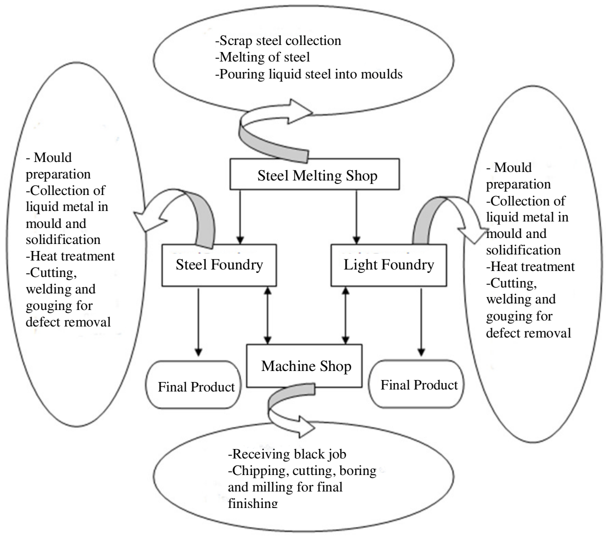

Fig. 2. Interaction of various shops and operations in CFFP Plant

B. Factors for Migration Towards Efficient Fuel

The migration of an organization from liquid fuels to natural gas may be caused by many driving forces. Some of these factors regarding CFFP, are described below:

- Natural gas is cleaner fuel than LDO/HSD. It emits less pollution during combustion [27]. The amount of CO_2 emitted during combustion per billion BTU of natural gas is 117000 while 164000 units are emitted by the burning of one billion BTUs of LDO [28].
- Spreading of oil (HSD or LDO) at workplaces results in hazardous conditions that might lead to an accident while this problem does not exist in natural gas and provides higher safety at the workplace.
- In liquid fuel, two types of air supply, primary and secondary are required. Primary air is required for atomization and secondary air serves the purpose of combustion [29]. Thus the electricity required to supply primary air through blowers driven by electric motors is saved.
- Moreover, due to the primary and secondary air supply in furnaces, the excess air is much higher in oil fired furnaces and boilers. Increase in the quantum of air input to any furnace increases the quantum of flue gasses resulting into a corresponding increase in heat loss to the atmosphere.
- In winters, LDO being a high viscosity fuel gets more viscous and sticky [30]. Thus, heating is required for LDO for making it suitable for transportation.
- Transportation of liquid fuel is done either by rail or by road and many times its arrival delays due to unpredictable and uncontrollable reasons. On the other hand, natural gas is transmitted through underground pipelines without any interruption.

C. Challenges Encountered During Switching

Although there might be a need to switch from a traditional fuel to a new one, this conversion may not be simple. Some of the major challenges that can be occur during the switching are:

- The time of completion required for conversion usually poses the most critical factor, as all the equipment cannot be closed simultaneously in the plant, affecting production activities. So there is always a trade-off between how many types of equipment can be taken up for fuel switching in different phases.
- Appropriate scheduling and budgeting are required for fuel switching that should include target production, equipment availability, criticality of jobs, and other relevant parameters.

D. Fuel Switching Process

In order to compare the energy consumption, we have considered the production of foundry shops of CFFP for the last four years and the corresponding fuel consumed for the respective production of castings. The main steps to perform the switching of fuel are:

- Collection of yearly production data. Analysis of energy consumed from various types of fuels.
- Conversion of fuel consumption according to calorific values or any other common unit for comparison.
- Calculation of SEC and yearly comparison of SEC.
- Calculation of fund saving (if any) due to SEC reduction.

In this case study of fuel switching, the major work is changing the combustion system including pipelines, air supply system, and control system for regulation of fuel and air, and burners that are compatible with new fuel. The activities performed for the evaluation of performance are:

1) Collection of Yearwise Production Data

Before the financial year 2012-2013 the enterprise was using only liquid fuels for manufacturing products. The conversion of fuel in CFFP started in 2012-2013 and natural gas completely replaced old liquid fuel by 2015-2016. The enterprise production for these years is shown in Table I:

TABLE I. PRODUCTION DATA

Financial Year	Casting Production (MT)
2012-13	5716
2013-14	5807
2014-15	5792
2015-16	5212

2) Analysis of Energy Consumed from Various Types of Fuels

In this section, energy data in various forms related to both foundry shops has been analyzed for the last four years. The combined total energy consumption for both foundry shops along with combined production outcome is shown in Table II.

3) Conversion of Fuel Consumption to Calorific Values

The calorific values of all the fuels used (LDO, HSD, LPG or natural gas) are different and in order to compare these fuels and further energy performance, the consumption of various forms of fuels are converted to the same unit based on their calorific values. As the contribution of electricity does not alter the foundry operations and requires a fixed amount of electricity, therefore, to precisely evaluate the variation of other fuel with respect to production, electricity is excluded from the calculations of energy consumption for production operation. The details of calorific values for all the fuels used for conversion and calculated million kilo-calories (Mn-kCal) are shown in Table III.

TABLE II. ENERGY CONSUMPTION

Form of Energy	2012-13	2013-14	2014-15	2015-16
Power (10^5 KWH)	49.28	52.67	49.56	41.62
LDO/HSD (10^3 Liters)	3872	2601	127	0
LPG (Metric Tones)	989	26.1	4.14	0
Natural Gas (10^5 SCM)	4.27	27.44	45.03	37.01
Production (MT)	5716	5807	5792	5212

TABLE III. FUEL CONVERSION INTO CALORIFIC VALUES

Fuel type in base unit of consumption	Equivalent KCal	Equivalent Mn-kCal
LDO/HSD	1 Litre=11700	1 Litre=11700/10^6
LPG	1 Ton=11300	1 Ton=11300/10^6
Natural gas	1 SCM=9880	1 SCM=9880/10^6

4) Calculation of SEC and Yearwise SEC Comparison

The efficient working of the enterprise or its energy performance can be compared by comparing the yearwise SEC per unit of turnover. SEC is defined as the ratio of total energy consumed to the total units of production or turnover:

$$\text{SEC}=\text{Total energy consumed}/\text{Total turnover}$$

The consumption of various fuels by the organization in Mn-KCal for the compared four years with casting production is shown in Table IV.

TABLE IV. SEC PER YEAR

Financial year	Energy consumption (Mn-KCal)	Casting production (MT)	SEC (Mn-kCal/MT)
2012-13	60696.86	5716	10.62
2013-14	57837.35	5808	9.96
2014-15	46022.32	5792	7.95
2015-16	36565.88	5212	7.01

E. Analysis and Decision Making for Fuel Switching.

In this phase, the SEC for old fuels used before switching and natural gas used after switching are compared. It has been noticed that there is a significant reduction in SEC by the use of natural gas. The percentage share of various types of energy consumed by the enterprise during the financial years starting from 2012-13 to 2015-16 has been analyzed and represented in Figures 3 and 4. The details of energy consumption before and after fuel conversion are described below.

1) Before Switching

Figure 3 shows the distribution of energy for 2012-13. During this financial year, LDO/HSD had the main share in energy consumption with a percentage of 69.76% of total energy consumption. The electricity consumption was 6.53% of total energy consumed whereas LPG and natural gas had

17.21% and 6.49% respectively. For the financial year 2013-14 (Figure 4), the share of LDO/HSD decreased to 48.79%, electricity was at 7.26 %, whereas natural gas share increased to 43.46% and LPG was not consumed.

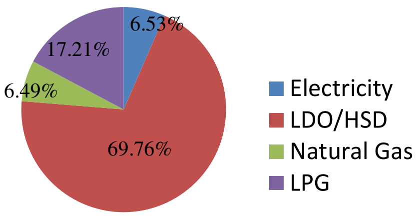

Fig. 3. Fuel consumption in 2012-13

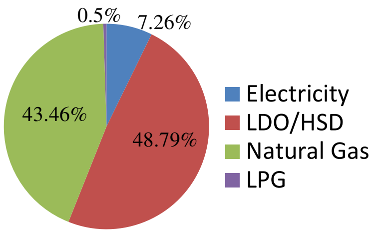

Fig. 4. Fuel consumption in 2013-14

2) *After Switching*

In 2014-15 (Figure 5), natural gas had the largest share in energy consumption, contributing around 88.47% of total energy, the electricity consumption was 8.48% and the use of LDO/HSD was limited to only 2.95%. During 2015-16 (Figure 6), the natural gas had completely replaced all other fuels and has contributed 91.08% in total energy consumption, while the share of electricity was 8.92 %.

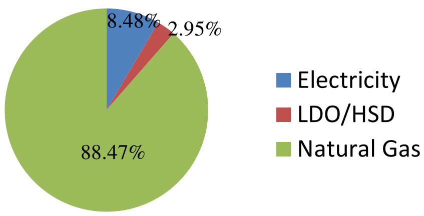

Fig. 5. Fuel consumption in 2014-15

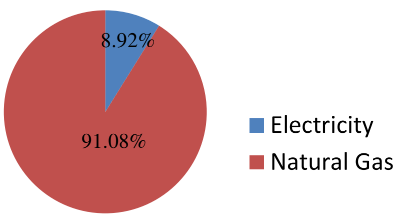

Fig. 6. Fuel consumption in 2015-16

3) *Evaluation of Performance on the Basis of SEC*

Figure 7 shows that the SEC decreased by the increase in the use of natural gas. For the time period from 2012-13 to 2015-16, the SEC fallen from 10Mn-KCal to around 7Mn-KCal per Ton of turnover.

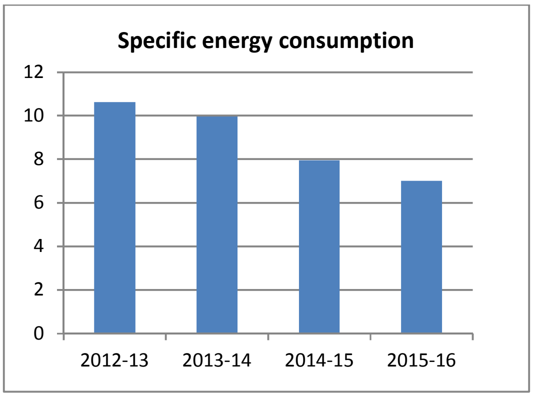

Fig. 7. Specific energy consumption

4) *Fund Savings due to Reduction in SEC*

Savings compared to the base year 2012-13 have been estimated. In case the enterprise had not used natural gas and consumed the old fuel, the specific consumption was bound to remain almost equal to that of the year 2012-13. But with the increased use of natural gas over the years, SEC reduced. The SEC for the year 21012-13 was 10.62Mn-KCal per metric ton and this value for 2013-14 was 9.96Mn-KCal per metric ton. The difference came out to be 0.66Mn-KCal per metric ton. The significance of this is that for manufacturing each metric ton of production output, the enterprise saved 0.66Mn-KCal. The actual saving of natural gas in the year 2013-14 is computed by multiplying the difference of SEC with the turnover of the year 2103-14 and dividing it by its calorific value. The result will give the physical quantum of the natural gas saved. Thus, CFFP saved 387984SCM of natural gas in 2013-14. By considering the rate of natural gas approximately to Rs. 25 per SCM, it gives the actual monetary saving of Rs. $97\cdot10^5$ for 2013-14 alone. The savings for the other years have been worked out in a similar way and are listed in Table V.

TABLE V. SAVINGS DUE TO SEC REDUCTION

Year	Saving in SEC with respect to 2012-13	Savings in Mn-KCal	Savings of natural gas in SCM	Approx. Savings**
2013-14	0.66Mn-Kcal*	3833.28	387984	Rs. $97\cdot10^5$
2014-15	2.67Mn-Kcal*	15464.64	1565247	Rs. $391\cdot10^5$
2015-16	3.61Mn-Kcal*	18815.32	1904385	Rs. $476\cdot10^5$

* Per MT of turnover.

** Considering Rs. 25 per SCM of natural gas.

V. CONCLUSION

In this paper, conversion from various fuels to natural gas has been analyzed. Factors acting as driving forces and challenges for switching of fuels have been defined. It is evident from the case study that the use of natural gas in replacement of three fuels, namely LDO, HSD and LPG by CFFP has resulted in significantly lower consumption of energy identical production. Natural gas has been found to be cheaper, cleaner and more energy efficient fuel for the foundry under consideration. This improvement of energy efficiency directly reduced the enterprise's energy bills and also saved a significant quantity of natural reserves which were to be consumed if natural gas was not used. Thus, the current paper serves as a guide to foundry enterprises to review the use of existing fuel and explore the possibility of fuel switch.

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