2nd INTERNATIONAL WORKSHOP
ADVANCES IN CLEANER PRODUCTION
"KEY ELEMENTS FOR A SUSTAINABLE WORLD: ENERGY, WATER AND CLIMATE CHANGE"

Solutions for Energy Savings and Environmental Compliance Leading to Cleaner & Lower Cost Production

A. J. Basu[a], V. B. Dutta[b], D. Datta[c]

a. *JNE Consulting Ltd., Hamilton, ON, Canada*
b. *Advenient Technology, CA, USA*
c. *M&I Power Technology, Inc., Mississauga, ON, Canada*

Abstract

Present dilemma is with 'how to manage the global warming resulting from energy guzzling manufacturing sectors like power, petrochemical, steel, mining, and minerals industries'? Although these operations are essential to sustain the global economy, their impact on climate change can't be ignored. This paper addresses scientific and engineering approach to transform these operations and minimize their impact in our eco-friendly world. The primary objective is in providing total solution for energy savings in vibration and noise reduction for achieving safe, energy-efficient, and cleaner production. The methodology has been substantiated with several practical examples that have been implemented in North America, Europe and other parts of the world, where 15% ~ 25% energy savings have been achieved.

"Noise and Vibration" are common occurrences in operations of critical equipments in the process and heavy industry sector. These symptoms are indication of turbulent airflow and wasted energy. This paper focuses on "optimization of airflow in plant draft systems" and therefore minimizing the use of energy to generate same amount of work. A number of design innovations for reducing turbulence and flow separation ensuring streamlining of airflow in the draft system and uniform loading on fans in the draft (forced or induced) system have been discussed. The present work elaborates on design optimization for achieving energy efficiency and environmental compliance leading to cleaner production – realized by modifying plant draft systems and fan systems using CFD simulation tool, including mathematical modeling and numerical simulation.

Implementation of this technology has improved the health & safety constraints in the industry. The outcomes of selected case studies are included for demonstrating the energy savings and the corresponding financial return through the proposed design innovations. In addition, improved inlet and outlet conditions of any pollution prevention equipment (*e.g.*, SCR, ESP, FGD) facilitate enhancement of environmental compliance of these equipments. Further, stream lining the plant draft system has also demonstrated improvement in process yields, improvement in fan and related equipment life as well as flexibility to use lower grade raw materials (*e.g.*, high ash content coal in boilers).

The major design innovation is the aerodynamic diffusion system. In the mining industry, such solutions when integrated with CFD modeling would enhance the total systems approach. This is a growing area and gradually receiving corporate attention for conducting studies in improved ventilation system management. Finally, various solutions and technical approach recommended by the authors integrate the three pillars (Economics, Environment, and Society) of sustainable development and helps the operating companies to meet their Corporate Social Responsibility.

Keywords: Aero-acoustics, Energy-efficiency, Computational Fluid Dynamics (CFD), Cleaner Production

1 Introduction

Dependence on fossil fuel and global awareness of the impact of carbon emission are now forcing the heavy industry sector to start looking into efficient ways of energy management, conservation and storage. This paper elaborates on the "methodology to reduce energy consumption in industrial production facilities (e.g., Power and Process Plants, Mines) without compromising on quality and productivity". The focus is to minimize energy waste, which often results into 'noise and vibration'.

Energy Efficiency (EE) is a tool for waste minimization (reduction of energy abuse) and contributes to the concept of Pollution Prevention (PP) and Cleaner Production (CP). Achieving the goals of PP and CP leads to compliance to Industrial Ecology (IE) and Sustainable Development (SD) frameworks as shown in Figure 1.

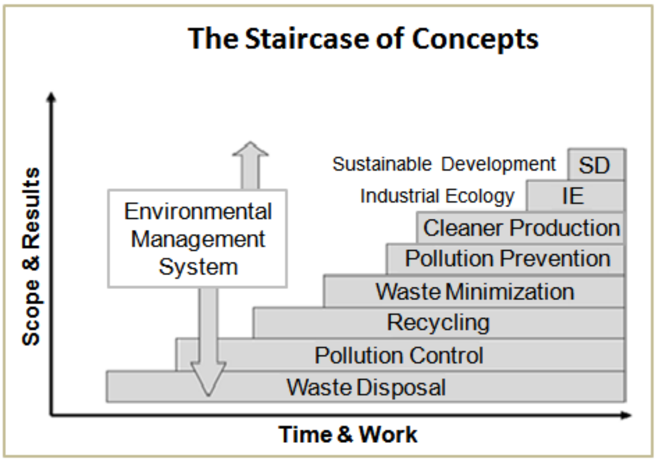


Fig. 1: The staircase of concepts for environmental management systems [1,2]

The process demands waste minimization and the focus of this paper is minimization of waste of energy, which often results into noise and vibration related health hazards. UNEP Division of Technology, Industry and Economics (DTIE) introduced an integrated CP-EE methodology in 2004 for promoting achieving energy efficiency as the direction to CP objective[3]. The project is operating successful in countries like China, Vietnam, India, Hungary, The Czech Republic and Slovakia, while other member countries are now accepting it. However, the CO_2 emissions data published by Carbon Dioxide Information Analysis Center[4] suggests that the main contributeurs are none of these above

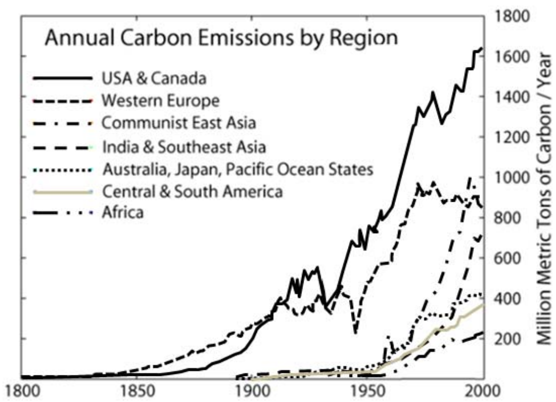


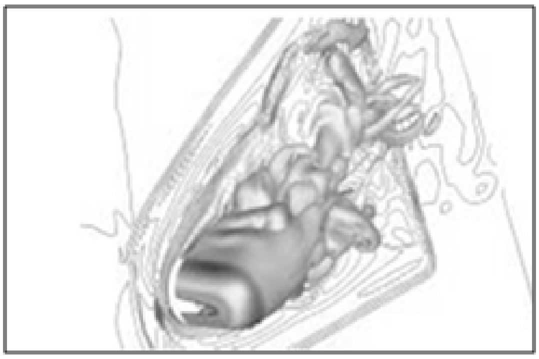
Fig. 2: Annual CO_2 emissions for non-overlapping regions covering the Earth[4].

Countries but North America and Europe. USA is viewed as the highest polluter to the greenhouse effect, where coal contributes to 49.7% as energy generating source while producing a total of 4.06 Billion MWh of electricity. The industry consumes 33% of this total energy[4]. Therefore, USA should be the first priority where the integrated CP-EE methodology to be introduced. However, realistic implementation of such methodology is only possible if they offer short term economic gains to corporations.

The authors have taken these considerations while providing practical engineering solutions for energy savings and environmental compliance resulting in cleaner & lower cost production. The successful performance of the installations has benefited several multinational companies in developed and developing nations[5]. The approach in heavy industrial sector is primarily involved into minimizing pressure losses in a plant draft or process ventilation system. Design innovations are implemented in lowering system resistances to process media (air or gas). Lowered system resistance in turn leads to reduced fan shaft power and motor HP requirement. Electric motors are the primary drivers of all air moving equipment. Industrial motor systems represent approximately 25% of American Electricity consumption and 64% of energy use in all industrial sectors in USA [6]. Typically, High Efficiency motors and VFD in combination are used to reduce energy wastage and improve energy efficiency. However, this paper emphasizes achieving energy efficiency through integration of aerodynamics and acoustics engineering (a field known as aero-acoustics) by reducing turbulence in airflow and improving air flow distribution in more uniform manner.

Aero-acoustics is a relatively developed technology predominant in aero-space and automotive industry and implemented for reduction in noise and vibration [7]. The authors are working in applying this technology in optimizing air or gas flow through a plant draft or process ventilation system using computational fluid dynamics (CFD) for simulating airflow through the system. The simulated airflow analysis is then used to implement design modifications for improving the system efficiency and reducing energy loss, thus meeting the cleaner production goal. This approach of EE implementation process also reduces noise and flow induced vibration leading to increased operational life of the draft/ventilation system and performance of pollution prevention equipment in an industrial process system.

CFD is the primary tool for aero-acoustics study and implementation. A number of sophisticated software such as, ANSYS CFX and FLUENT are widely used for this activity. Figure. 3 shows a typical output of such a study.



NOTE:
Turbulence in airflow and areas of noise and vibration are also clearly visible in this simulation model[8]. This type of simulation Direct Numerical Simulation (DNS) or Large Eddy Simulation (LES) requires very high end computational tools.

Fig.3: Velocity streamlines and airflow simulation around a side mirror of a car [8].

2 The Technology

The focus for this paper is energy management and optimization for achieving energy efficiency of ventilation (draft) systems in power, process, mining, and minerals. Operating units in these industry sectors are now required to implement various pollution prevention (PP) equipment for meeting "Cleaner Production" and "Occupational Health and Safety" mandates. However, performance of these pollution prevention equipment, such as, Self Catalytic Reducer (SCR), Electrostatic Precipitator (ESP), Bag House, Flue Gas Desulfurization (FGD), Dust collectors and scrubbers (for reducing respirabale dusts), depends on uniform distribution of the process media, which is air or flue gas. Moreover, lowering system resistance of a ventilation system or plant draft system allows either more airflow for the same fan shaft power or reducing the required fan shaft power for same airflow. Reduction in fan shaft power helps in saving energy requirements and reduces operating cost of a plant draft or process ventilation system. The energy savings and operating cost reduction could be computed using the following equations:

$$HP_s = (Q \times p_s)/(6350 \times \eta) \quad (1)$$

$$OC_s = HP_s \times 0.746 \times N \times \varepsilon \quad (2)$$

Where,

HP_s = savings in fan shaft power (HP)

OC_s = Annual savings in operating costs ($/year)

Q = airflow (cfm, 1 m^3/s = 2,118 cfm)

p_s = pressure loss (inch of w.g., 1 kPa = 4.04 inches of w.g.) savings in draft/ventilation system due to lowering of system resistance by aero-acoustically engineered system modification

η = draft/ventilation system efficiency (%, typically 65-80%)

N = Total operating hours in a year

ε = unit cost of electricity usage ($/kWh)

Technology implementation requires integration of fan engineering, knowledge of the relevant process engineering (domain knowledge), and control and instrumentation (for verification and validation) expertise. A typical process includes the following steps:

1. Identification of the problem areas (examples as follows)
   a. Air-critical system, i.e., additional airflow is required to achieve optimized production)
   b. Flow induced noise and vibration (indicates turbulent airflow)
   c. Product output (e.g., iron ore pellets) is of non uniform nature (indicating non-uniform distribution of airflow)
2. Create a model of the problem area and subject to airflow simulation
3. Review the simulated results, and look for areas of non-uniform airflow distribution and identify areas of possible improvement
4. Prepare design modifications for improving the flow condition and reducing system loss
5. Detailed engineering and fabrication of the designed components for airflow improvement
6. Implementation of the design solution on site, and verification and design validation of the supplied solution
7. Confirmation and record of airflow improvement and energy savings

Please note that implementation of aero-acoustics in the current context is a two stage process, not a Direct Numerical Simulation (DNS) for noise prediction as it is used in aerospace and automotive industry. The procedure in practice is:

1. Aerodynamic modeling of the system
2. Design a silencer system assuring uniform airflow through the silencer eliminating turbulence in the system (airflow turbulence is the primary cause of noise and vibration in a fan system).

Noise attenuation calculation is based on the insertion loss due to acoustical insulation and aerodynamic performance of the system.

The advantage of this coupled system analysis is that is does not require very high end computing, as required for DNS or Large Eddy Simulation (LES). It utilizes conventional engineering knowledge of silencer design and placement of the designed silencer in the uniformly distributed less turbulent air flow stream (determined by CFD simulation of the system). Therefore, domain knowledge of the process is the key requirement rather than the knowledge of aerodynamic modeling.

3 Real Life Application and Case Studies

3.1. Modification of FD Fan Discharge Duct:

Based upon the drawings *provided by an electric* power plant, the improved flow methodology was implemented at the relevant segments of the draft systems and results were verified using CFD analysis as shown in Figure 4. After studying of the existing details flow abnormalities were identified in the existing ducts at various locations. In order to achieve the potential savings several areas were recommended along with design modifications. Modification of FD Fan discharge duct is shown here as an example. A pressure drop savings of 39 mm WC was demonstrated, resulting into 12 ~ 14% of power savings as compared to existing design.

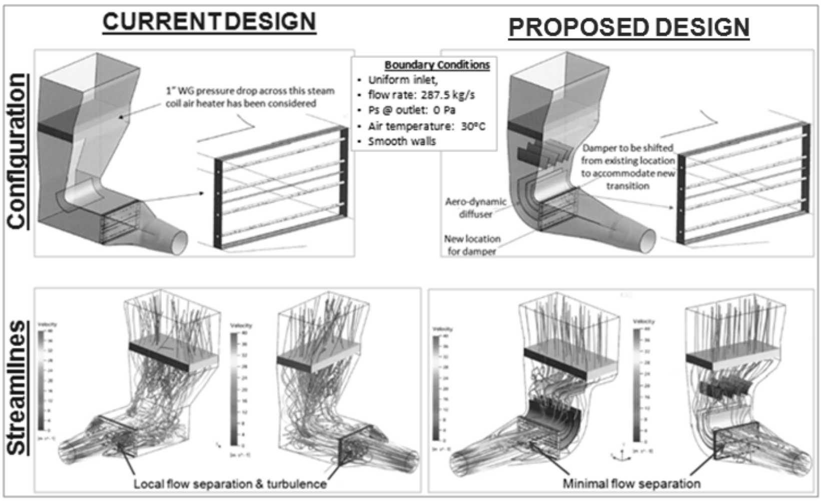


Fig.4: Modification of FD Fan Discharge Duct

In order to avoid flow induced vibration caused by blades of damper under stratified flow condition, damper location was shifted closed to elbow. Modifications include conical bullet in fan diffuser. Please note the long turning vanes/aerodynamic vanes to effectively convert velocity pressure to static regain.

Potential for Carbon Credit along with reduction in mechanical vibration and regenerative noise levels were demonstrated.

3.2. Application in integrated steel plants:

A typical process flow of a steel plant is shown in Figure 5. Expected overall benefits could either be 15 ~ 25% savings in energy cost or 5 ~ 10% of additional gas/air flow to increase the productivity can be achieved. This is from the fans alone, due to lowered fan shaft power. Further, a reduction of pressure loss in the draft system (approximately 4 ~ 6″ of w.g. or 10-15 mbar per fan system) can also be achieved.

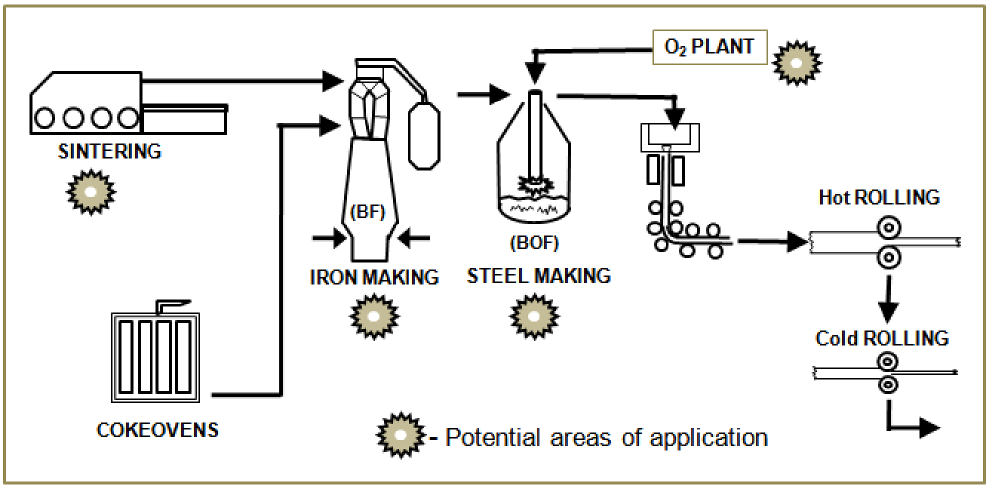


Fig.5: Potential areas of application in an integrated steel plant

ADDITIONAL BENIFITS:

- Due to improper flow distribution in the Baghouse, one may observe the neck erosion because of poor distribution of dust generated and collected in the bag. Also the dust particles escape. This contributes to frequent maintenance shutdown and bag changes. Such problems can be minimized.
- Uniform flow distribution also improves fluidized bed conditions in sintering, thus improving quality and throughput.
- Due to uneven distribution of flue gas - large sizes dust particles have tendency to cause uneven erosion of duct & contributing to high pressure drop (viz. drag velocity). This can be improved in BOF gas recovery and other areas.
- Reduced noise and vibration due to uniform and less turbulent airflow through the duct systems.
- There are silencers with ID fan systems in the BF Casthouse areas and BOF Gas Recovery area in addition to the Sinter Plant silencer. Aero-acoustics of all the silencers embedded in the relevant ID fan systems could be improved.

3.3. Application in coal power plants:

Coal fired power plants are primary candidates for CP-EE framework applications. Plant draft system in a coal fired power plant involves three major components:

1. Primary air fan system supplying combustion air
2. Forced draft fan system for boiler operation

3. Induced draft fan system for exhausting flue gas from the boiler to the environment through the following PP equipment
    a. SCR (for NO_x reduction)
    b. ESP (for fly ash and dust reduction)
    c. FGD (for scrubbing SO_2 in the flue gas system)

Figure 6 illustrates the process of power generation and air/gas flow in a coal fired plant. A typical ducting scheme for air/gas flow through a boiler system is also shown in Figure 7. Airflow optimization using CFD simulation of these duct system identifies areas of aerodynamic improvement. Implementation of these aerodynamic improvements reduces turbulence and pressure loss in the system and improve acoustical functioning of the duct system. Some typical results were included in Figure 4.

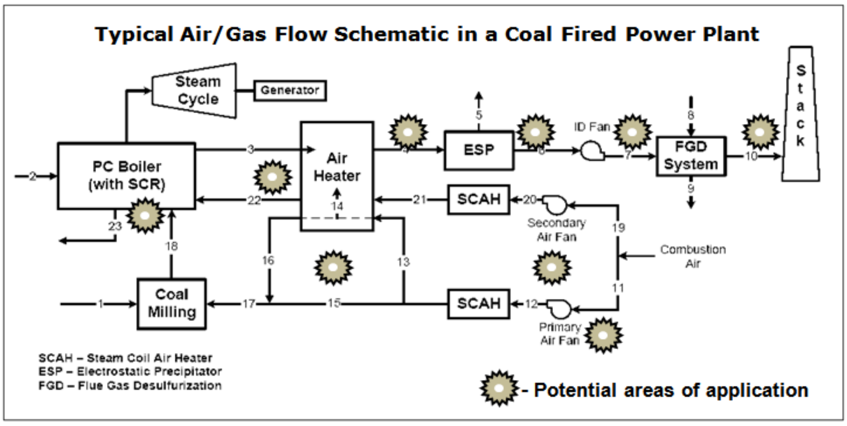


Fig.6: Potential areas of application in a coal power plant

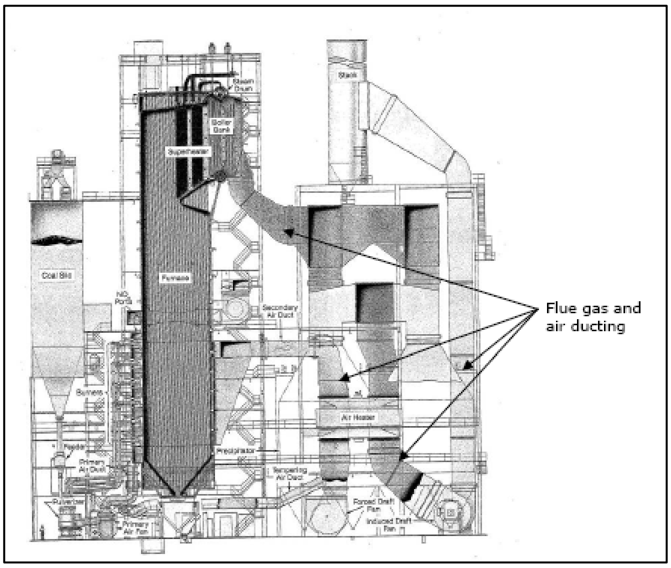


Fig.7: Air and Flue Gas ducting in a typical coal or oil fired power plant [9]

3.4. Another application of CFD simulation for facilitating CP

Respirable dust is a major health hazard in mine and tunnel development process. CFD simulation of a tunnel development ventilation scheme allows the engineers and planners to visualize and identify the areas of high velocity and turbulent region so proper dust suppression and respirable dust control measures could be implemented. Moreover, modification to the ventilation duct system would also help in reducing fan shaft horse power requirement and reduction in energy requirement. Figure 8 shows an example of a typical tunnel heading with turbulent air flow.

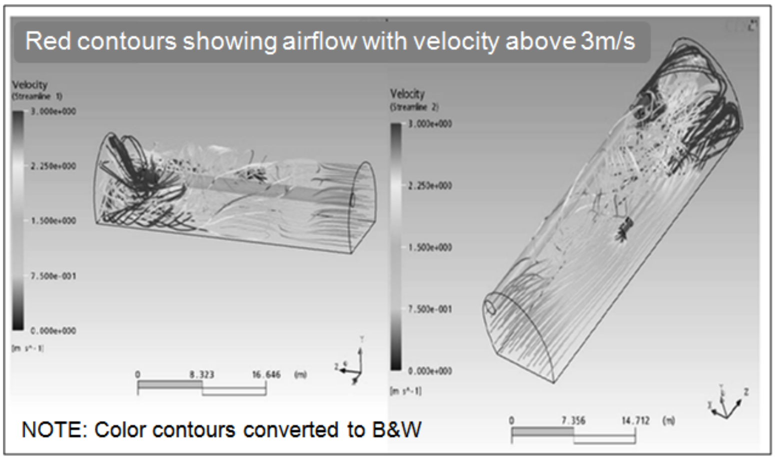


Fig.8: Airflow simulation for a tunnel development ventilation scheme identifying turbulent zones susceptible for hazardous concentration of respirable dust

Airflow requirement for tunnel or metal mine ventilation depends on diesel equipment being used (100 cfm per BHP) for proper dilution of contaminants from diesel emission, which is also a health hazard. Therefore, efficient air management with proper equipment demand planning (ventilation on demand) would also reduce the amount of air required (Q in equation 1) and help in reduction of energy requirement.

4 Concluding Remarks

The above sections demonstrated the tools for achieving Energy Efficiency (EE) through aero-acoustics implementation to existing industrial process involving use of conventional energy resources (coal, oil, diesel and natural gas). CFD simulation is used as a diagnostic tool in understanding areas of improvement in an industrial process consuming conventional energy, and then energy efficiency is achieved by SMART engineering.

Causes and effects of global warming are well documented. The findings have been endorsed by several scientific establishments worldwide[10][11]. Since the greenhouse effect is due to emission of gases that rises into the atmosphere and traps sun's energy, and emission of gases is the result of generating energy by burning fossil fuels (*e.g.* hydrocarbons such as coal, oil, natural gas, petroleum) – the immediate technology challenges are to explore and improve alternate sources of energy generation to reduce dependency on fossil fuel[12]. It has taken a two prong approach, where at one end nature's energy, like wind, air etc., as alternate source of energy are being trapped and on the other end attempts are being made towards smart management of the conventional energy from fossil fuels. Various aspects of this two prong effort are shown in Figure 10.

Fig.10: Current energy efforts to reduce Greenhouse Effect.

The source of conventional energy is through burning of fossil fuels and this is the largest source of emissions of carbon dioxide contributing to global warming. Given the advantages inherent in fossil fuels, such as their low cost availability and relative dependence together by the existing heavy industrial infrastructure, they are still likely the fuel of choice in energy production in the near to medium-term future. Increase in global fossil carbon emission numbers are captured by International Centre for Hydrogen Energy Technologies[13] and shown under Figure 11 below. This figure also highlights the contribution from cement production. It should be noted that there other concentrations of heavy industries like Iron & Steel, aluminum, petro-chemical refineries, captive power plants which are not included in this list – contributing equally, if not more to carbon emission.

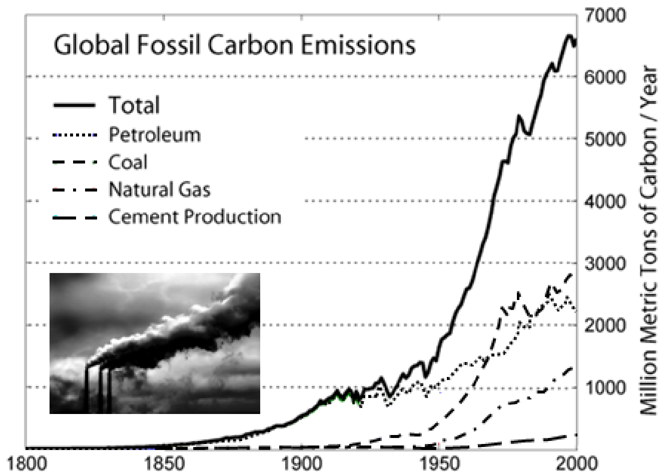


Fig.11: Progressive contribution of various fossil fuels on global carbon emission.

Dependence on fossil fuel and global awareness of the impact of carbon emission are now forcing the heavy industry sector to start looking into efficient ways of energy management, conservation and storage. This paper elaborates on the methodology to reduce energy consumption in industrial production facilities (e.g., Power and Process Plants, Mines) without compromising on quality and productivity. The focus is to minimize energy waste, which often results into "noise and vibration" and "respirable dust" related health hazard.

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