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Energy Monitoring of Process Variables and Optimization of Nozzle Section in Sustainable Plastic Injection Molding

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Abstract: With respect to the improvement of energy monitoring and optimized nozzle section in Sustainable Plastic Injection Molding (EMONS-PIM) to achieve the Cost-Effective end product for the industries. During the process of molding of Polymethyl Methacrylate (PMMA) the effects of parameters in terms of energy consumption needs to get determined. Energy efficiency is a severe issue because of the increasing energy costs as well as the correlated environmental impact. The major parameters which are concentrated in terms of energy are melting and molding temperature, holding and cooling time, screw rotational speed and nozzle temperature. The highest impact on energy consumption is produced by cooling time and nozzle temperature. Simulation is done among the process parameters and the equivalent energy dissipation is recorded at each instant of time. Several hydraulic injection molding machines are considered for energy monitoring process and found out the energy saving opportunities. The optimization of nozzle section and energy monitoring is simulated using the software's CATIA and MATLAB. In CATIA the effective nozzle section is performed and the relevant analysis is performed. In MATLAB the process of energy consumption reduction is concentrated and the parameters which are considered for the process of simulation analysis are sum rate, bit error rate, convergence plot and energy consumption. The materials which are considered in the PIM process are thermoplastic polystyrene, thermoplastic acrylonitrile butadiene styrene and thermoplastic polyvinyl chloride. To perform the process of comparative analysis the end results of the proposed EMONS-PIM method is compared with the earlier researched like AntLion Optimization, PSO-MSQPA and MLGS-PIM.

Index Terms: *Plastic Injection Molding (PIM), Energy Monitoring, Optimized Nozzle Selection, CATIA and MATLAB*

1. Introduction

The method most often employed to create plastic components is injection molding. Almost all types of applications employ plastic, from domestic things to space research, transportation to packaging, medications to electronics, and building construction to sports. Generally speaking, injection molding is a process that shapes polymers into the desired shape by heating the plastic and forcing it into the mould cavity while under pressure. The proper shape of the plastic is produced either by a thermosetting chemical reaction or through thermoplastic cooling. As the plastics industry's product quality standards have gotten more stringent, identifying the optimal injection molding processing parameters for the creation of new goods and improving present quality products has become an important field of research. Setting and fine-tuning method variables is recognized as an effective way to improve the uniformity of molded components without spending additional money on mould maintenance. However, since it depends on a number of variables, such as the molding material, the design of the mould and product, and the molding system, optimizing process variables is a broad and complicated problem [1].

The industry demands obtaining sufficient productivity with high-caliber output. However, it becomes challenging to do both at once because of the many variables involved in the plastic molding process. One must set high standards for work since productivity is directly linked to time and for a quality result. Human energy consumption is a significant factor in both productivity and quality [2]. Additionally, it has been found through a review of the literature [3], [4] and trips to several plastic processing facilities that man and machine interaction is crucial to the production of plastic goods. The amount of energy used by people tends to increase at different points, energy that may be conserved and used for tasks that are more suitable. Therefore, it is necessary to make assumptions about the factors or characteristics that lead to a consumption of human energy [5].

In the current researches, simulation provides an opportunity to forecast the characteristics of the PIM process that concentrates mainly on cost effective experimental studies. Large discrepancies between simulation findings and actual process data are possible

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because of the complexity of the PIM process, the dynamic machine response, the constraints and simplifications of simulation approaches. For instance, the identical process parameter values are used in physical tests on an electrical injection molding machine and prior research simulation using the programmed Cadmould 3D-F. The comparison of the theoretical and as well the implementation process weights shows, for certain configurations of the parameter values, the implementation could reflect the general curve of the connection among parameter values and weights. However, in adding to a consistent error that existed for all configurations, a considerable discrepancy between measurements and implementation might be shown for assured values of the process parameters [6].

It is challenging to design an injection-molded item and to machine it, but it is particularly challenging to design the feeding system, which comprises the sprue, the runners, and the gates. Despite the fact that several ideas and theories have been created in the last few decades regarding plastic injection modeling, there is no guarantee that high-quality machining and a matching high-quality molding can be produced. An injection-molded part's design and machining are traditionally carried out by accumulated expertise. However, the need for the highest quality is now necessary due to the constantly growing client expectations for high quality and affordable products. The majority of damaged and faulty plastic moulds are the result of improper feeding system design. In order to correct these design flaws and enable plastic molders to produce better-quality plastic components with lower investment and greater production, the most efficient injection nozzle should be created. The anti-backflow, anti-leakage, and pressure compensated (ABLPC) injection nozzle was discussed in earlier researches. They claimed that when compared to a normal nozzle, the ABLPC nozzle performed better. Other modeled flow during the extrusion of difficult cross-sectional profile. They employed the Polyflow program's Bird-Carreau viscosity model for study. As a result, they created a technique to address the issue of imbalanced polymer melt extrusion from the mould. They found that the speed distribution at the cross-section of the mould exit was uniform.

During the plastic injection process, the flow behavior of polymers flowing from the nozzle portion of a 150 tone injection machine is improved. They improved the polymer flow for various process characteristics and materials by using optical fiber probes with an infrared spectrometer technique. In order to compare the predicted outcomes with the actual results, in others works modeled the extrusion process used in the compounding of a polyamide material at a double-screw extruder machine. They used the Polyflow and Fluent tools to create the numerical modeling. To remove flow abnormalities, the extruder head's geometry was adjusted. By using the finite element approach, the simulation of the filling step for low pressure aluminum injection molding. They demonstrated how simulations were found to accurately depict patterns like a rise in the pressure needed to fill moulds as temperatures fell.

In order to replicate the viscoelastic polymer melt packing process in injection molding created a 3D thermal model. They demonstrated that as melt temperature rose, the density gradually reduced while the exact values of the initial normal stress differential increased significantly. The initial normal stress difference and density were greatly improved by the high holding pressure. Additionally, they said that the current 3D thermal model was a useful tool for modeling the packing processes of visco-elastic polymer melts in real-world settings. When analyzing the micro-properties of typical micro fluidic chips using micro injection molding, they developed a technique that might leverage the expected inaccuracies. They reached the conclusion that the filling of micro properties was significantly impacted by the heat transfer coefficient. A fourth order viscosity tensor describes he characterizes the fibber-induced anisotropic flow behavior in a unique modeling approach for reactive injection molding. Their research revealed that the experimental results supported the cavity pressure and fiber orientations [7]. In order to improve the process PIM and to reduce the drawbacks of the earlier researches, in this research the concept of energy monitoring and optimized nozzle section is concentrated and the contribution of the research is described.

1.1 Research Contribution:

This research work mainly focused on the study of the selection of effective process parameters to maintain minimum energy consumption and that's leads to attain high quality in the end product of the molded parts. Through the selection of optimal process parameters the energy consumption of the molded parts are reduced greatly that's helps to achieve good quality in end product. On the other hand the optimization in nozzle section is concentrated to achieve effective overall performance. To perform this experimentation the CATIA and MATLAB software's are used and the parameters which are considered for the analysis are sum rate, bit error rate, convergence plot and energy consumption.

2. Related Works

In [8] the author Zhaoyan Fan et.al designed a unique self-powered wireless sensor which converts temperature and pressure in an injection mould cavity into ultrasonic pulses with help of Temperature Sensitive Oscillator and a Threshold modulator. The threshold modulator was created as a circuit with negative differential resistance; it produces pulses by a piezo ceramic element. This helps to obtain accurate results with minimum variation. In [9] In order to calculate the size and placement of cooling channel the author Fauzan proposed a formula by optimization with the CR/PE parameter where product cooling temperature is uniform. The simulation results revealed that high percentage correction factor all interpolations. In [10] the author Hsin-shu et.al employed PA66 polymer composites instead of metal material due to high stiffness, high strength. This material enhances the structural characteristics of molded parts with minimum consumption of energy. In [11] the author Zhiwei Jiao et.al explained the automatic control of the internal circulation two-platen Injection Moulding Machine. Because internal circulation cylinders are employed in the new injection molding process, the external circulation is eliminated and the hydraulic system is minimized, resulting in significant energy savings.

In [12] to minimize the energy consumption the author Hanieh t.al, examined the factors which affecting the energy consumption in hydraulic Injection moulding machine. Hence, the number and size of motors and pumps, as well as their power factor, influence the peak power of energy consumption. The energy consumption profile of the tested machines demonstrated that there is no typical behaviour shared by the hydraulic IMMs during a single cycle of the process, as each of them exhibited a distinctive and entirely separate energy consumption profile. In [13] the author Isaac Meekers et.al optimized the process parameters to minimize the energy consumption without affecting quality of products. Using Design of Experiments, the cooling period and nozzle temperature were shown to have the biggest effects on energy usage. None of the parameters within the chosen processing windows had any effect on the mass or length of the part. In [14], the author Jack B. Tranter et.al Assess the effect of specific process variables on the energy usage of the injection moulding of acrylonitrile butadiene styrene (ABS). To create experimental table, Design of Experiments (DOE) was employed. The findings demonstrated that the major variation in energy usage is caused by changes in the cycle time (holding and cooling time).

In [15] Using prototype cartridges, the author Luis Ortiz et.al proposed and verified a simulation model for heating with a surface-mount resistor. The size and orientation of this model can be improved for the cartridge's channels and resistors to achieve other design objectives or maximise thermodynamic efficiency. In [16] the author María G. Villarreal developed a multi-criteria solution through simulation methods which use meta-modelling and design of experiments to reduce the number of simulation assessments. Due to this, it is desirable in instances where lengthy simulations, such those used to investigate the injection moulding process, are required. In [17] the author Shuo Wang et.al, designed a Fuzzy-PID Controller for servo injection molding system. The brand-new Fuzzy-PID controller can significantly lower the packing pressure tracking error and also provides manufacturing precision and low economical. In [18] In order to conduct a thermal investigation of the HDPE material flow the author Baris Gurel et.al examined the nozzle section of the 160-ton Ekin 160-B coded plastic injection machine. Four possible geometries were analysed, each with a genuine system dimension (r-NG) and additional design dimensions (NG1, NG2 and NG3). The analysis's findings demonstrated that the third (NG3) design contained the best flow. In [19] the author Anil Kumara analysis the rectangular shaped plastic component (four gates) with mould flow plastic simulation software. Using CAD/CAM and Mouldflow analysis will improve the calibre of the work in the production of the mould and lower the amount of manufacturing errors.

3. Materials and Methods

3.1 Injection molding:

The most commonly used plastic processing technique is injection moulding because of its effectiveness and low cost. Injection-molded components are found in a variety of goods, including mobile phones, computers, and automobiles. Polymer materials can be formed using this manufacturing approach to create components with intricate shapes. The three major components of injection moulding machines are: (1) a clamping device for mounting the mould, (2) The polymer must be fed into the injection unit, melted inside the barrel at a certain temperature, and then injected into the mould to achieve the desired shape, (3) Control unit where the settings of the moulding process are adjusted. A hopper, drier, and mould temperature control unit (TCU) are examples of additional peripheral pieces of equipment needed for the injection moulding process.

3.2 Injection molding process:

Mold closing (clamping), melt injection (packing), cooling, mould opening, and ejection are the five basic operational phases of injection moulding. The first step in the procedure is filling the heated injection barrel of the injection moulding machine with the plastic material (often in the form of granules) from the hopper. By transferring heat from the heated cylinder and shearing the granules with a moving screw, the heated barrel causes the granules to melt. The molten material is transported to the chamber in front of the screw tip as the screw revolves. After this plasticization stage, the polymer is inserted into the cavity of the mould, which is molded to be the negative of the component to be created. A high melt pressure is retained in the packing/holding stage after the filling process that incorporates compressing the melt in the cavity, to make up for shrinkage as much more molten plastic is poured into the cavity. When 95% of the mould is loaded, the compression stage, also known as the transition from the injection to the holding phase, takes place. The plastic part then solidifies as a result of chilling the mould with the help of cooling passages included into the mould. The cooled solid portion is ejected at the procedure' conclusion. When the mould, which has two halves, is opened, the portion is ejected. Repeating the entire procedure is conducted.

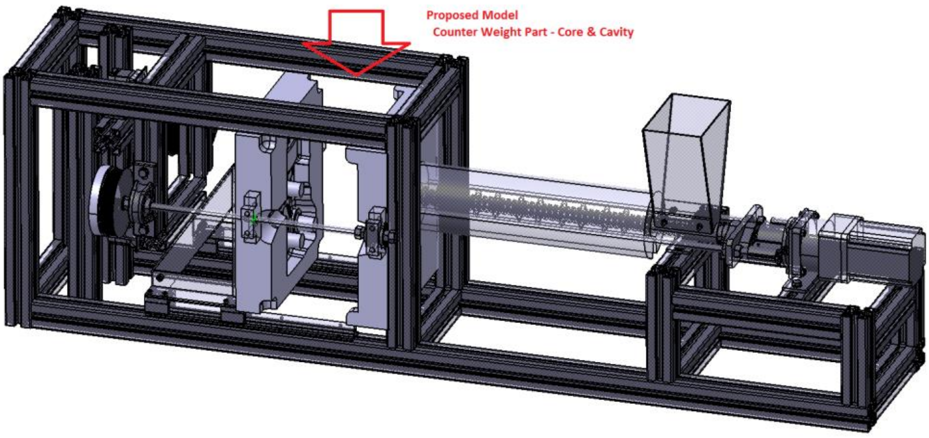

Fig. 1 – PIM Machine with Core and Cavity

4. Proposed EMONS-PIM Processes

The proposed EMONS-PIM mainly concentrates on the energy consumption reduction during injection molding and optimization in nozzle section. The major sections which are present in the proposed EMONS-PIM are energy consumption during injection molding, impact of process parameters on quality criteria, optimized nozzle section in PIM process and the details about the P20 mold steel material properties.

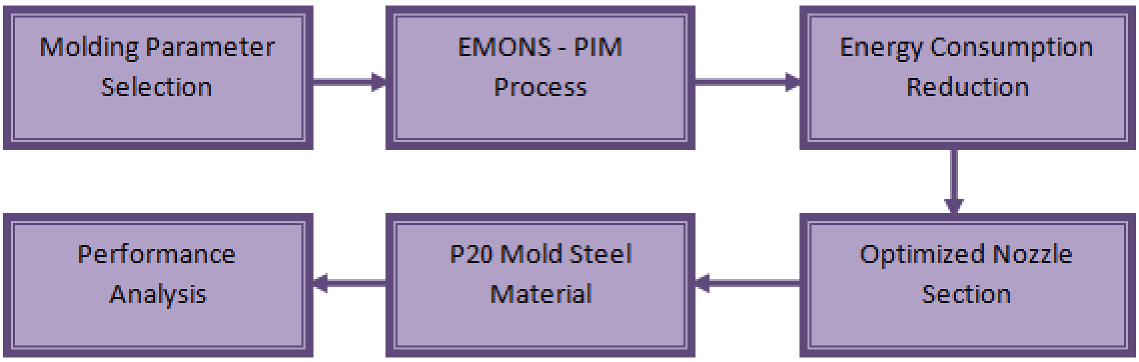

Fig. 2 – Workflow of the Proposed EMONS-PIM Process

4.1 Energy Consumption during Injection Molding:

Numerous researches on sustainability in this sector have been done as a result of the significant energy consumption of the injection molding industry. The energy requirements for manufacturing processes vary depending on the condition of the equipment and the stage of production. The various machine states are as follows: (1) Off (no energy usage), (2) Start/ramp up (energy demand surges when components are turned on and heated up), (3) Idle (pretty constant energy usage following the ramp up period and machine is prepared to start production), and (4) Operations (the energy utilized for the value additional process) [6]. Throughout the many stages of the injection molding process, energy is dispersed. Analyses by Spiering et al. have looked into the energy usage in relation to the injection molding of automotive components utilizing a hydraulic injection molding machine. According to the authors' calculations, the machine's drives accounted for about 50% of the energy used, while the cooling of the mould used 20%, pressured air supply 10%, the heating of the spindle 10%, and material transport and drying another 10%. Using a common test known as the Euromap-60.2, Mianehrow et al. aimed to identify the most significant factors influencing energy usage during injection molding of polypropylene. A TES-3600 power analyzer was used to examine the energy profile of six hydraulic injection molding machines over the duration of one full cycle of testing. The Specific Energy Consumption (SEC) was shown to be significantly impacted by the cycle time. This can be done by decreasing the cooling and holding times. By lowering the cycle time, the result shows the reduction in operation time of the motors and pumps. Table 1 displays the results demonstrating this relation.

Table 1 Connection of Cycle time and SEC

PIM Machine	Time (s)	SEC (kWh/kg)
A Type	110	0.755
B Type	120	0.780
C Type	120	0.925
D Type	100	0.748
E Type	120	1.739
F Type	80	0.650

Followed by that the second investigation is carried out in which they used dual electrical energy signatures to evaluate the injection molding of Polybutylene Terephthalate (PBT) pieces. By comparing the power curves between one processing cycle to a cycle without material (air filling), the dual energy signature method can identify process components that contribute value (VA) and non-value (NVA). The value-adding and non-value-adding components were identified by projecting the power profile graphs of the two processing cycles. The findings revealed that a lower value addition efficiency of 23% was achieved in terms of energy. Here a new effort is performed to increase the process' efficiency by cutting the process time by making the most of the holding and cooling times, as well as by lowering the power level. In comparison to utilizing the suggested parameters, they discovered that the cycle time might be decreased by 7.7 s. This would result in time savings of about 15% and energy savings of about 15%. To determine a correlation between the process factors and the energy usage, empirical approach is introduced in earlier researches. Controlled variables were clamping pressure, injection pressure, holding pressure, decompression pressure, injection speed, and dosing speed. SEC was selected as the response variable, and it was computed using the cycle time, power, and mass. Every 0.1 s, power usage was recorded. The throughput was found to be the noteworthy factor affecting energy consumption after calculating the SEC values and after determining the power consumption. According to modification in the process parameters alone had a negligible effect on energy consumption since the SEC was dominated by fixed power and the factors had little effect on cycle duration or throughput.

4.2 Improvement is Quality by varying the process parameters:

Studies on numerous quality parameters are available in addition to the extensive study on energy usage in the field of PIM process. The cycle time is viewed by manufacturers as crucial to their success. However, it is also essential to provide superior quality at the lowest possible product cost based on client demand. Mechanical properties, dimensional conformance, and surface appearance are a few examples of quality traits in injection moulding. Response Surface Methodology (RSM) was used to optimize the injection moulding process variables. RSM refers to a group of mathematical and statistical methods that are helpful for assessing and modelling engineering issues. The temperature of the mould, the injection pressure, and the rotational speed of the screw were the parameters that were changed. The findings demonstrated that values closer to the goal values for the part length and width were accomplished by raising the mould temperature and injection pressure.

Six input parameters—mould temperature, packing pressure, packing time, injection time, and melting temperature—were examined by Huang et al. for their effects on the surface quality of the injection-molded part. Simulations of the injection moulding procedure utilizing a PC/ABS blend at various parameter values were created using the P20 mold steel programme. The mould temperature, melt temperature, packing pressure, packing time, and injection time were shown to be the most important variables. Numerous researches have looked into the prospect of lowering the energy used during injection moulding using both empirical modelling and parameter adjustment. However, it appears that there are few studies that simultaneously consider part quality and energy use. When striving to reduce energy use, quality must be taken into account because sustainability cannot be attained without consideration of the three pillars of economics, the environment, and society.

4.3 Optimized Nozzle Section in PIM Process:

In this research, the referenced nozzle shape refers to the nozzle utilized in the Ekin 160-B coded injection machine of 160 tones, depicted in Fig. 3 and 4 shows the structural and dimensional views, of the nozzle section. In Table 2, its technical specifications are listed. Through the use of CATIA software the analysis is performed and the flow in the nozzle region of the research is optimized.

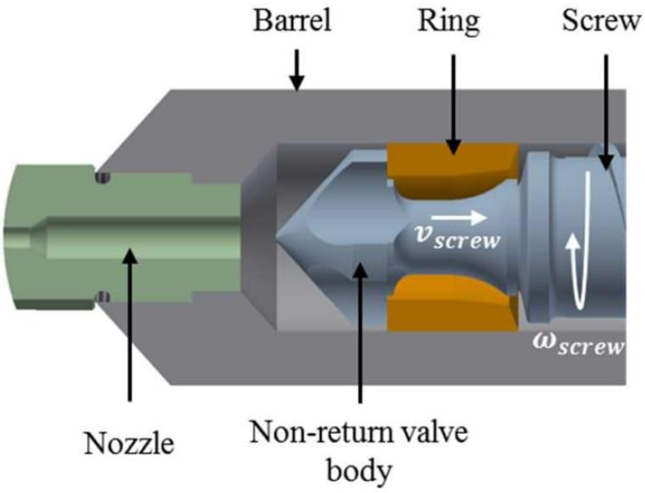

Fig. 3 – Structural View of Nozzle Section

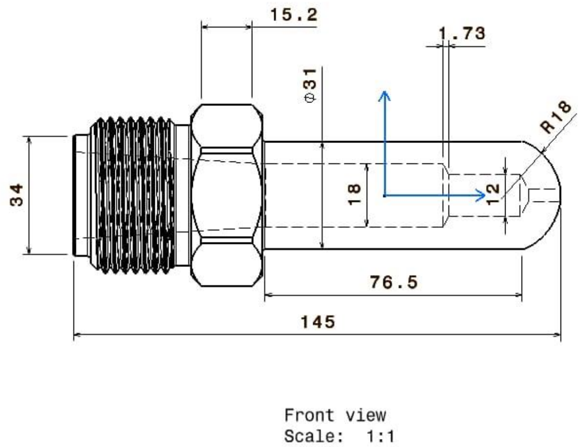

Fig. 4 – Dimensional View of Nozzle Section

In the analysis, high-density polyethylene (HDPE), which is primarily utilised in the production of plastic items, was used. Table 3 lists its parameters at 150 MPa of pressure and 200 °C of temperature. The best process characteristics for optimising flow in the nozzle are listed in Table 4. As a result, the actual nozzle geometry is modified geometrically (r-NG). Then, for the flow optimization, three alternative geometries (NG1, NG2, and NG3) are obtained. Finally, an evaluation and comparison of the results were performed. Several researches are used in this research as a reference for resolving mathematical equations. The balance equations for the finite volumes approach are quantitatively determined in the CATIA software, including the ones for continuity, momentum, energy, and the Bird-Carreau viscosity model:

Continuity equation

$$\nabla . u = 0 \qquad (1)$$

Momentum equation

$$\rho \frac{\partial u}{\partial t} - \nabla . \eta (\nabla u + (\nabla u)^T) + \rho u . \nabla u + \nabla p = 0 \qquad (2)$$

Energy equation

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial P}{\partial t} + k \nabla^2 T + \eta \Phi \qquad (3)$$

Bird-Carreau viscosity model

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)[1 + (\lambda \gamma)^2]^{\frac{(n-1)}{2}} \qquad (4)$$

Where γ denotes a scalar quantity that can be determined using the strain rate tensor's constituents, as follow:

$$\gamma = \sqrt{I_2 / 2} \qquad (5)$$

Where I_2 is the second invariant of the strain rate tensor as

$$I_2 = \sum_i \sum_j \gamma_{ij} \gamma_{ji} = \gamma_{xx}^2 + \gamma_{xy}^2 + \gamma_{xz}^2 + \gamma_{yx}^2 + \gamma_{yy}^2 + \gamma_{yz}^2 + \gamma_{zx}^2 + \gamma_{zy}^2 + \gamma_{zz}^2 \qquad (6)$$

The Bird-Carreau viscosity model was utilised to resolve the viscosity equation because it provides more precise and consistent results when simulating polymer flows. With the CATIA programme, these equations are discretized using the Simple Algorithm

Table 2. Technical Properties of the PIM

Properties	Value
Mounting Diameter (mm)	34
Nozzle Diameter (mm)	12
Chamber size (cm^3)	229
Nozzle Weight(g)	170
Injection rate(g/s)	89
Plasticizing Rate (g/s)	42
Injection Pressure(MPa)	137
Screw Speed (rpm)	0.50
Screw Stroke (mm)	185
Clamping force(kN)	1425

Table 3. Properties of P20 Mold Steel

Properties	Value
Young's Modulus N/m2	2e11
Poisson Ratio	0.3
Material density, ρ (kg/m3)	7861
Thermal Expansion KDeg	1.17e-5
Yield Strength N/m2	2.5e8

Table 4. Properties of the analysis process

Properties	Value
Inlet Pressure, $P_{in} (MPa)$	137
Inlet Temperature, T_{in}(℃)	210 (483k)

Nozzle Material	P20 Mold Steel
Nozzle Wall	Adiabatic Wall

4.4 P20 Mold Steel Material Properties:

In this research the P20 mold steel is used to perform the process of nozzle selection and as well in this section the typical composition, the coefficient of thermal expansion, and other properties with temperature and hardness are detailed.

Typical Composition of the P20 Mold Steel:

Table 5 - Typical Composition

C	Mn	Si	Cr	Mo
0.33	0.80	0.65	1.75	0.40

In general, the P20 mold steel is so versatile and it is one among the low-alloy tool steel that can able to provide better toughness even in the reasonable strength levels. This kind of steel is normally employed in PIM process based mold cavities and as well for die casting of zinc. The maintenance of pre-hardened condition of P20 mold steel is about 300 HBW and its coefficient of thermal expansion is shown in table 6 and the other material properties of P20 mold steel is given in Table 7.

Table 6 - Coefficient of Thermal Expansion

Temperature, °F	in/in °Fx10-6	Temperature, °C	mm/mm °Cx10-6
70 - 200	6.7	21 - 93	12.0
70 - 500	7.2	21 - 260	12.9
70 - 1000	7.6	21 - 538	13.7

Table 7 – Material Properties of P20 Mold Steel

Parameters	Values
Density	0.284 lb/in3 (7861 kg/m3)
Gravity	7.86
Elasticity	30x106 psi (207 GPa)
Thermal Conductivity	24 BTU/hr/ft/°F (41.5 W/m/°K)
Ability	60 - 65% of a 1% carbon steel

The other essential characteristics that need to get analysis the properties of the P20 mold steel is its stress relieving process, hardening process and annealing process. At the initial stage of the heat treating instructions stress relieving is carried out the shows the pre-hardening condition of the materials where the process of hardening heat treatment is not employed here hence that is more complicated one. The thermal stress which gets released at the time of heating the material up to 900°F (482°C) continued by that the equalizing operation is performed for the time duration of one hour per inch of 25.4mm thickness where the cooling is continued until it reaches its ambient temperature. Currently the critical temperature of the material reaches up to 1405°F (763°C) at this condition the process of preheating and quenching is carried out. Preheating process is carried out at the range of 400°F per hour (222°C per hour) to 1150-1250°F (621-677°C) once after this process it gets equalized. The maximum heat achieved in the preheat process is 1550°F (843°C) and then it get soaked for 30 minutes where its inch of thickness in the current stage is 25.4 mm. Secondly at this level quenching is initiated where gas pressure is increased up to 150-125°F (66-51°C) and the oil quenching pressure is increased up to 900°F (482°C) and equalized in air to 150-125°F(66-51°C). Currently at this stage the process of tempering is carried out. The current temperature is hold to 1 hour per until is reached the inch of thickness to 25.4 mm and it is maintained in same temperature to 2 hours and then cooled to reach the normal temperature and the tempering temperature and the hardness values are shown in table 8.

Table 8 - Tempering Temperatures and Hardness

Temperature	HRC	Temperature	HRC
400°F (204°C)	48-49	1000°F (538°C)	39-40
600°F (316°C)	46-47	1100°F (593°C)	33-34
800°F (427°C)	43-44	1150°F (621°C)	30-31

At this level the process of annealing is initiated and it is process in the heat range of 400°F per hour (222°C per hour) to 1450°F (788°C) where to reach the thickness of 25.4mm inch the temperature is maintained maximum of the time period of two hours. Then the cooling process is started slowly to reach its normal temperature. These are the specific properties of the P20 mold steel and it is not suitable for other materials. These are the major details about the heat treatment process parameters which are involved in our researches.

5. Simulation Experimentations

For the process of experimentation the software's which is used are CATIA and MATLAB R2021b. In CATIA the analysis is done for the materials like as polystyrene, acrylonitrile butadiene styrene and polyvinyl chloride for P20 Mold Steel and its properties shown in the table 9.

Table 9 – Properties of P20 Mold Steel

Description	Polystyrene	ABS	PVC
Load Pressure (Mpa)	137 Mpa	140 Mpa	145 Mpa
Efficiency (%)	97%	94%	90%
Energy Consumption (%)	Low	Medium	High

5.1 CATIA Analysis

5.1.1 Materials Properties applying in CATIA platform

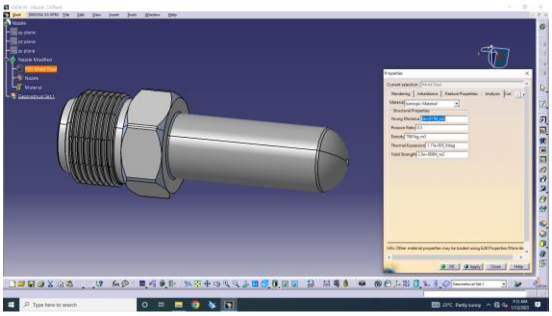

Fig. 5 - Materials Properties applying

5.1.2 Simulation and Analysis Section in CATIA

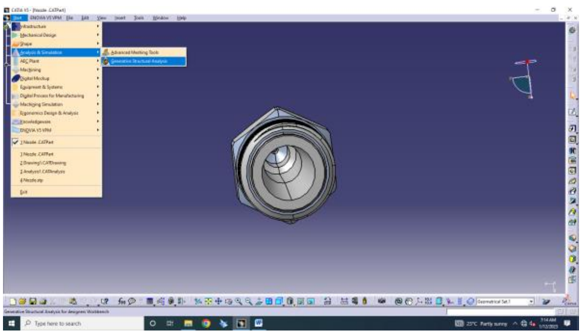

Fig. 6 - Simulation and Analysis Section

5.1.3 Clamp – Nozzle Restraints

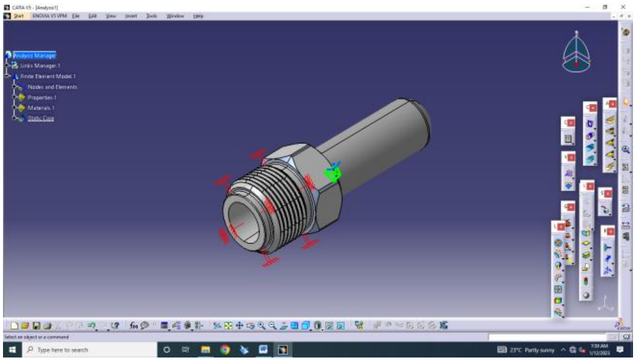

Fig. 7 - Clamp and Nozzle Restraints

5.1.4 Load Applied

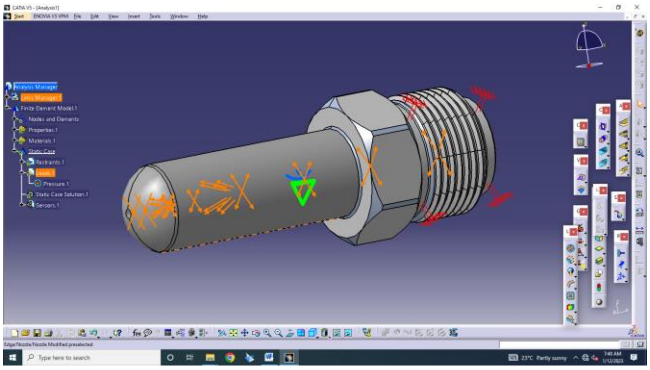

Fig. 8 - Load Applied

5.1.5 Mesh Visual

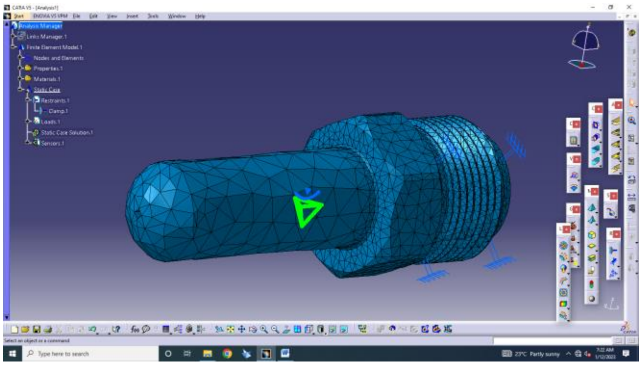

Fig. 9 - Mesh Visual View

5.1.6 Von Mises stress

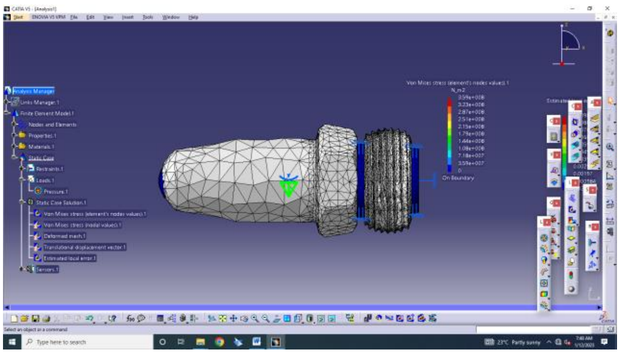

Fig. 10 - Von Mises stress

5.1.7 Stress Principal Tensor

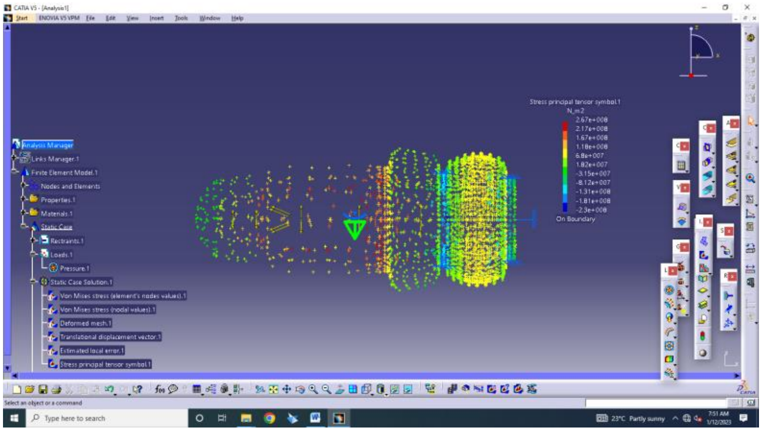

Fig. 11 - Stress Principal Tensor

5.1.8 Translational displacement Vector

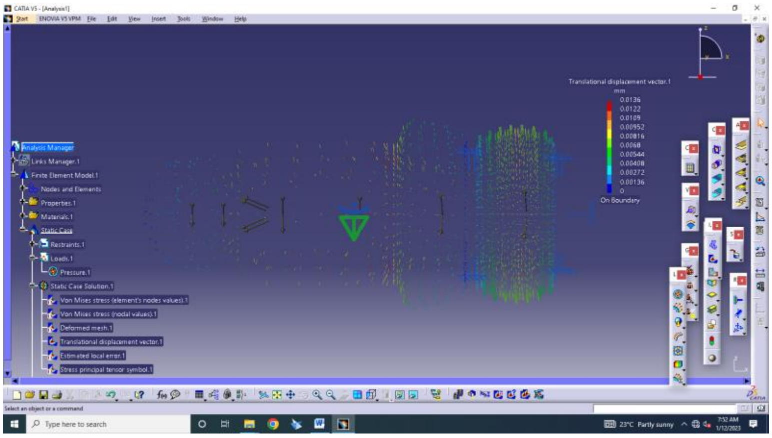

Fig. 12 - Translational displacement Vector

5.2 MATLAB Analysis

5.2.1 Sum Rate Calculations for varying iterations:

In this segment the sum rate of the AntLion, PSO-MSQPA, MLGS-PIM and the proposed EMONS-PIM process is calculated for varying iteration such as 10, 20 and 30. Figure 13, 14 and 15 illustrates the sum rate calculations which are involved in the PIM process and as well its measures are analyzed in table 10, 11 and 12.

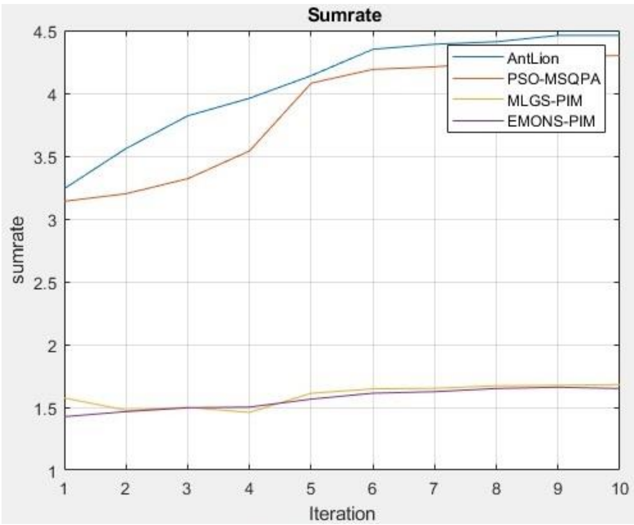

Fig. 13 – Sum Rate Calculation for Iteration 10

Figure 13 shows the performance of sum rate for the iteration of 10 counts and the analyses are performed for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. It is essential to reduce the sum rate to achieve effective end results during analysis. From the simulation and calculations it is understood that the proposed EMONS-PIM attain minimum sum rate and it is achieved with the help of effective energy monitoring and optimal nozzle section process. The numerical analysis of the sum rate calculation for 10 iteration counts are given in table 10.

Table 10 - Sum Rate Value Analysis for Iteration 10

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
1	3.24	3.14	1.57	1.42
2	3.56	3.20	1.27	1.46
3	3.82	3.32	1.50	1.49
4	3.96	3.54	1.45	1.50
5	4.14	4.08	1.61	1.56
6	4.35	4.19	1.64	1.61
7	4.39	4.21	1.65	1.62
8	4.41	4.25	1.67	1.65
9	4.46	4.29	1.67	1.66
10	4.46	4.30	1.68	1.65

From the above table, the sum rate performance for the iteration 10 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table it is established that the sum rate analysis of proposed EMONS-PIM is lower than the other methods where sum rate calculation of EMONS-PIM varies from 1.42 to 1.65 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (3.24 to 4.46), (3.14 to 4.30) and (1.57 to 1.68) respectively. So the sum rate is lower for the proposed EMONS-PIM using energy monitoring and optimized nozzle section process.

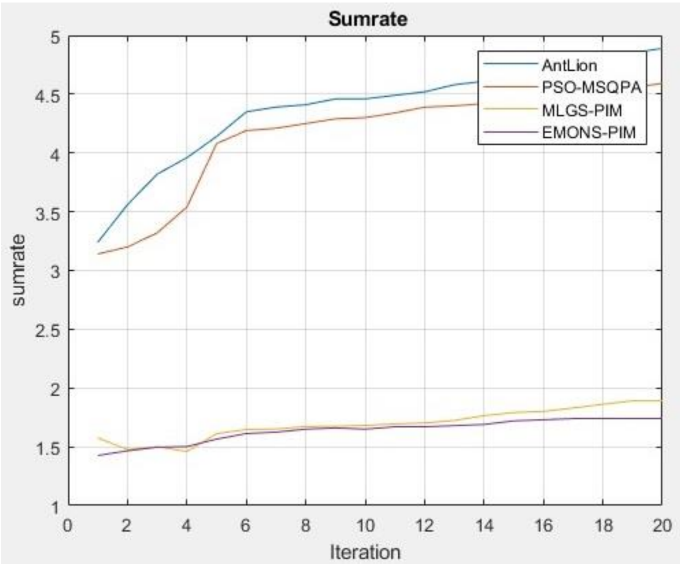

Fig. 14 – Sum Rate Calculation for Iteration 20

Figure 14 demonstrates the graphical representation of sum rate for the iteration of 20 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. To achieve minimum sum rate in this research energy consumption in the PIM process is reduced to the possible extent and optimization is performed in nozzle section. Using this process the proposed EMONS-PIM attain minimum sum rate when compared with the earlier researches in PIM process. The numerical analysis of the sum rate measurements for 20 iteration counts is given in table 11.

Table 11 - Sum Rate Value Analysis for Iteration 20

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
2	3.56	3.20	1.57	1.46
4	3.96	3.54	1.45	1.50
6	4.35	4.19	1.64	1.61
8	4.41	4.25	1.67	1.65
10	4.46	4.30	1.68	1.65
12	4.52	4.39	1.70	1.67
14	4.61	4.42	1.76	1.69
16	4.71	4.49	1.80	1.73
18	4.81	4.52	1.86	1.74
20	4.89	4.59	1.89	1.74

From the above table, the sum rate performance for the iteration 20 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the sum rate measurements of the proposed EMONS-PIM varies from 1.46 to 1.74 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (3.56 to 4.89), (3.20 to 4.59) and (1.27 to 1.89) respectively. So the sum rate is lower for the proposed EMONS-PIM than the earlier researches using energy monitoring and optimized nozzle section process.

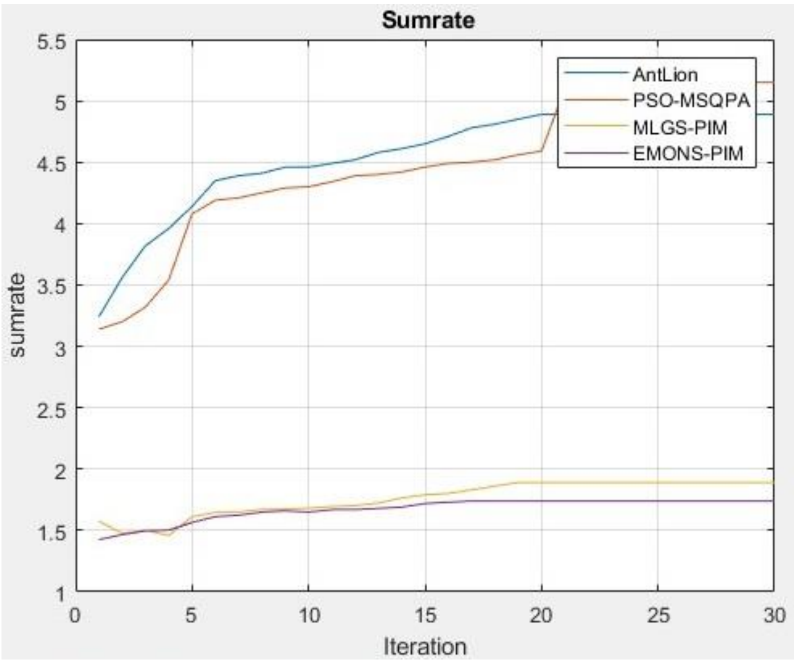

Fig. 15 – Sum Rate Calculation for Iteration 30

Figure 15 demonstrates the graphical representation of sum rate for the iteration of 30 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From figure its gets confirmed that the proposed EMONS-PIM produced lower sum rate during the time of PIM process and this results are attained with the help of reducing energy consumption and optimized nozzle section. The numerical analysis of the sum rate measurements for 30 iteration counts is given in table 12.

Table 12 - Sum Rate Value Analysis for Iteration 30

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
3	3.82	3.32	1.50	1.49
6	4.35	4.19	1.64	1.61
9	4.46	4.29	1.67	1.66
12	4.52	4.39	1.70	1.67
15	4.65	4.46	1.79	1.72
18	4.81	4.52	1.86	1.74
21	4.89	4.52	1.86	1.74
24	4.89	4.52	1.86	1.74
27	4.89	4.52	1.86	1.74
30	4.89	4.52	1.86	1.74

From the above table, the sum rate performance for the iteration 30 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the sum rate measurements of the proposed EMONS-PIM varies from 1.49 to 1.74 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (3.82 to 4.89), (3.32 to 4.52) and (3.82 to 4.89) respectively. So the sum rate is lower for the proposed EMONS-PIM than the earlier researches with the help of energy consumption reduction and as well optimization using nozzle section process.

5.2.2 Bit Error Rate Calculations for varying iterations:

In this segment the bit error rate of the AntLion, PSO-MSQPA, MLGS-PIM and the proposed EMONS-PIM process is calculated for varying iteration such as 10, 20 and 30. Figure 16, 17 and 18 illustrates the sum rate calculations which are involved in the PIM process and as well its measures are analyzed in table 13, 14 and 15.

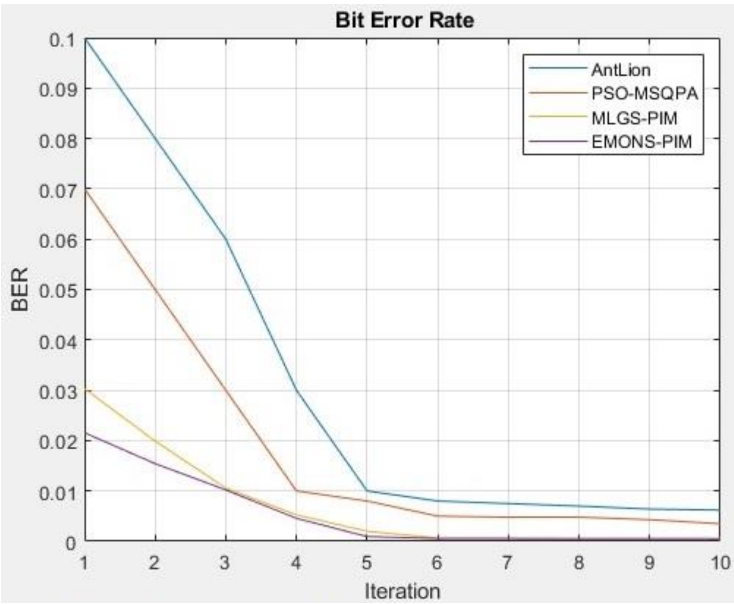

Fig. 16 – Bit Error Rate Calculation for Iteration 10

Figure 16 shows the graphical representation of bit error rate for the iteration of 10 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. To attain maximum overall performance it is very essential to reduce the bit error rate generation during the time of molding process for that purpose in the proposed EMONS-PIM, energy consumption reduction and optimized nozzle section is concentrated from the results it is proven that the proposed EMONS-PIM achieved minimum bit error rate when compared with other methods. The numerical analysis of the bit error rate calculation for 10 iteration counts are given in table 13.

Table 13 - Bit Error Rate Value Analysis for Iteration 10

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
1	0.1	0.07	0.030	0.015
2	0.08	0.05	0.019	0.0102
3	0.06	0.03	0.010	0.0046
4	0.03	0.01	0.0052	0.0009
5	0.01	0.008	0.0019	0.0005
6	0.008	0.005	0.00065	0.0005
7	0.0075	0.0048	0.00064	0.0005
8	0.0070	0.0048	0.00058	0.0005
9	0.0064	0.0043	0.00058	0.0005
10	0.0062	0.0035	0.00058	0.0005

From the above table, the bit error rate performance for the iteration 10 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the bit error rate measurements of the proposed EMONS-PIM varies from 0.015 to 0.0005 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.1 to 0.0062), (0.07 to 0.0035) and (0.030 to 0.00058) respectively. As an outcome of the bit error rate, the proposed EMONS-PIM attained lower value when compared with the earlier researches and it is reached using the energy monitoring and optimized nozzle section process.

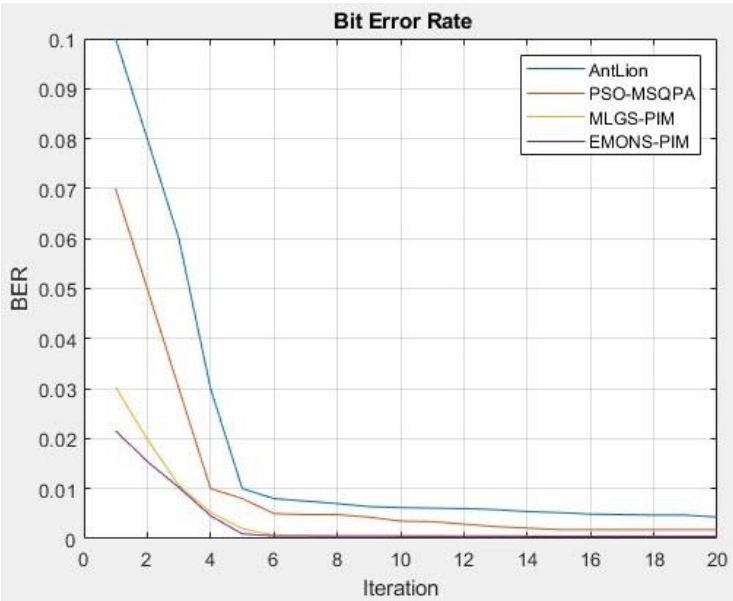

Fig. 17 – Bit Error Rate Calculation for Iteration 20

Figure 17 shows the graphical representation of bit error rate for the iteration of 20 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. Consequently attaining minimum sum rate is the plan to get the maximum performance and the proposed EMONS-PIM achieved that when compared with the other methods which are involved in the process of performance analysis which is achieved using the energy monitoring and optimized nozzle section process. The numerical analysis of the bit error rate calculation for 20 iteration counts are given in table 14.

Table 14 - Bit Error Rate Value Analysis for Iteration 20

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
2	0.08	0.05	0.0199	0.0154
4	0.03	0.01	0.0052	0.0046
6	0.008	0.005	0.00065	0.0005
8	0.007	0.0048	0.00058	0.0005
10	0.0062	0.0035	0.00058	0.0005
12	0.0060	0.0029	0.00054	0.0005
14	0.0054	0.0021	0.00053	0.0005
16	0.0049	0.0018	0.00049	0.0004
18	0.0047	0.0018	0.00049	0.0004
20	0.0043	0.0018	0.00049	0.0004

From the above table, the bit error rate performance for the iteration 20 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the bit error rate measurements of the proposed EMONS-PIM varies from 0.0154 to 0.0004 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.08 to 0.0043), (0.05 to 0.0018) and (0.0199 to 0.00049) respectively. From the end results it is proven that the proposed EMONS-PIM produced minimum bit error rate for iteration 20 counts when compared with earlier methods with the help of energy monitoring and optimized nozzle section process.

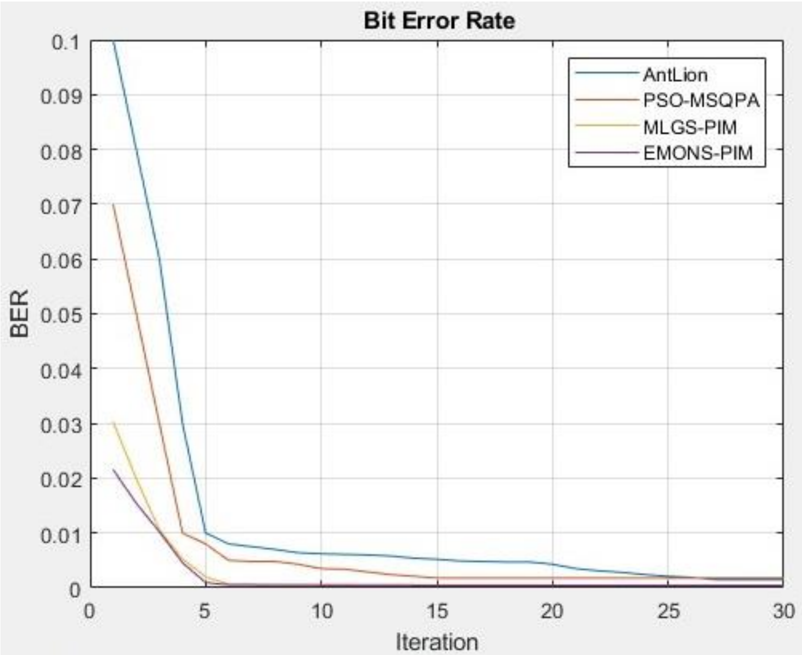

Fig. 18 – Bit Error Rate Calculation for Iteration 30

Figure 18 represents the graphical output of bit error rate for the iteration of 30 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From figure it is confirmed that the proposed EMONS-PIM attained minimum bit error rate when compared with others that's effectively leads to achieve maximum performance in the end product production. The numerical values of the bit error rate with 30 iterations are given in table 15.

Table 15 - Bit Error Rate Value Analysis for Iteration 30

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
3	0.06	0.03	0.0105	0.0102
6	0.008	0.005	0.00065	0.0005
9	0.0064	0.0043	0.00058	0.0005
12	0.0060	0.0029	0.00054	0.0005
15	0.0052	0.0018	0.00049	0.0004
18	0.0047	0.0018	0.00049	0.0004
21	0.0035	0.0018	0.00047	0.0004
24	0.0024	0.0018	0.00046	0.0004
27	0.0015	0.0018	0.00046	0.0004
30	0.0015	0.0018	0.00046	0.0004

From the above table, the bit error rate performance for the iteration 30 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the bit error rate measurements of the proposed EMONS-PIM varies from 0.0102 to 0.0004 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.06 to 0.0015), (0.03 to 0.0018) and (0.0105 to 0.00046) respectively. Accordingly to the end results it is understood that the proposed EMONS-PIM attained lower bit error rate for iteration 20 counts using energy monitoring and optimized nozzle section process.

5.2.3 Convergence Plot Calculations for varying iterations:

In this segment the convergence plot of the AntLion, PSO-MSQPA, MLGS-PIM and the proposed EMONS-PIM process is calculated for varying iteration such as 10, 20 and 30. Figure 19, 20 and 21 illustrates the sum rate calculations which are involved in the PIM process and as well its measures are analyzed in table 16, 17 and 18.

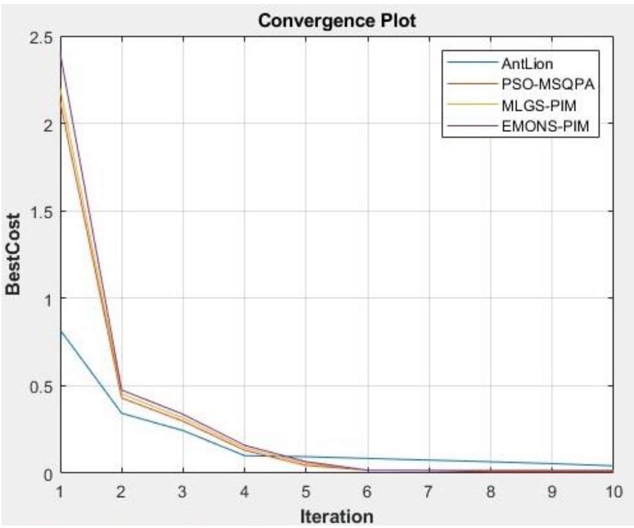

Fig. 19 – Convergence Plot Calculation for Iteration 10

Figure 19 represents the graphical output of convergence plot for the iteration of 10 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. Achieving maximum convergence leads to get done with precious end product for that purpose reduction of energy consumption and optimization in nozzle section is concentrated. From the results it is proven that the proposed EMONS-PIM better performance when compared with the other works. The mathematical values of the convergence calculation for 10 iteration counts are given in table 16.

Table 16 - Convergence Plot Value Analysis for Iteration 10

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
1	0.819	2.122	2.209	2.465
2	0.342	0.430	0.453	0.475
3	0.243	0.297	0.315	0.336
4	0.100	0.131	0.145	0.159
5	0.094	0.044	0.056	0.065
6	0.084	0.016	0.016	0.016
7	0.074	0.016	0.015	0.015
8	0.065	0.016	0.009	0.008
9	0.054	0.016	0.009	0.008
10	0.042	0.016	0.009	0.008

From the above table, the convergence calculation for the iteration 10 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the convergence measurements of the proposed EMONS-PIM varies from 2.465 to 0.008 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.819 to 0.042), (2.122 to 0.016) and (2.209 to 0.009) respectively. For this reason the end results achieved by the proposed EMONS-PIM is better than the earlier methods.

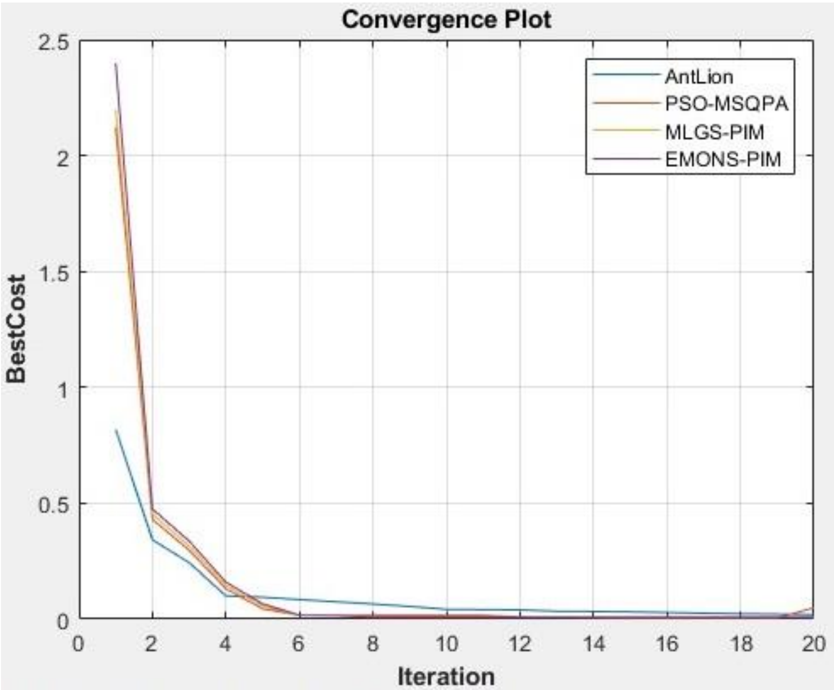

Fig. 20 – Convergence Plot Calculation for Iteration 20

Figure 20 represents the graphical output of convergence plot for the iteration of 20 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. Therefore attainment of maximum convergence is the purpose to attain better end results the proposed EMONS-PIM attains maximum convergence when compared with the earlier researches with the help of reduction of energy consumption and optimization of nozzle section. The mathematical values of the convergence calculation for 20 iteration counts are given in table 17.

Table 17 - Convergence Plot Value Analysis for Iteration 20

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
2	0.34	0.43	0.45	0.47
4	0.10	0.13	0.14	0.15
6	0.08	0.016	0.0163	0.0169
8	0.065	0.016	0.0094	0.0086
10	0.042	0.016	0.0094	0.0086
12	0.039	0.0098	0.0094	0.0086
14	0.033	0.0071	0.0094	0.0086
16	0.028	0.0054	0.0094	0.0086
18	0.023	0.0052	0.0094	0.0086
20	0.020	0.048	0.0094	0.0086

From the above table, the convergence calculation for the iteration 20 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the convergence measurements of the proposed EMONS-PIM varies from 0.47 to 0.0086 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.34 to 0.020), (0.43 to 0.048) and (0.45 to 0.0094) respectively. According to this calculation the achieved end results are better for the proposed EMONS-PIM when compared with the earlier methods.

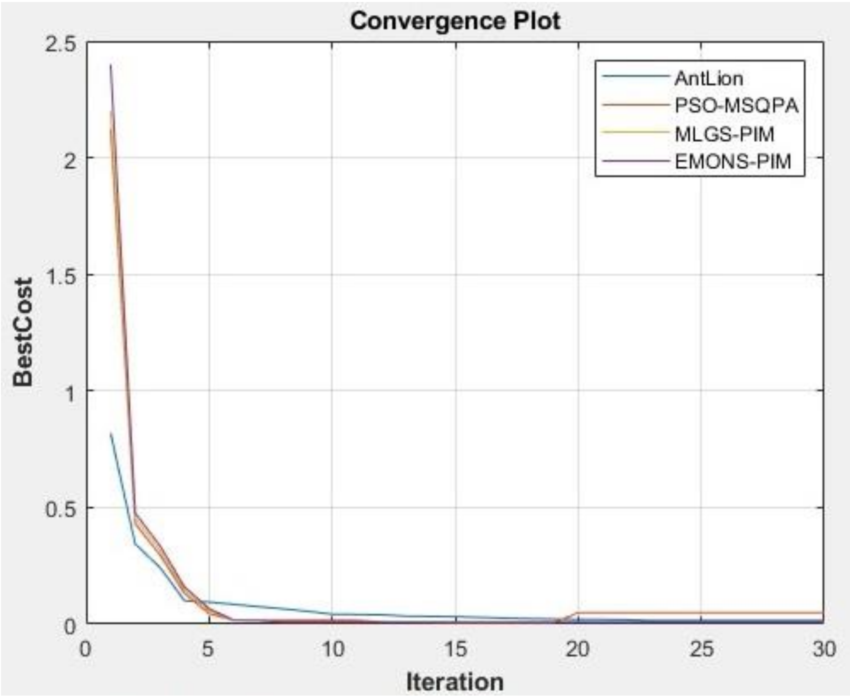

Fig. 21 – Convergence Plot Calculation for Iteration 30

Figure 21 denotes the output of convergence plot for the iteration of 30 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From figure it is proven that the proposed EMONS-PIM attain maximum convergence for iteration of 30 counts with the help of reduction of energy consumption and optimization of nozzle section. The numerical analysis of the convergence plot calculation for 30 iteration counts are given in table 18.

Table 18 - Convergence Plot Value Analysis for Iteration 30

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
3	0.24	0.29	0.315	0.3365
6	0.08	0.016	0.016	0.016
9	0.054	0.016	0.0094	0.0086
12	0.039	0.0098	0.0094	0.0086
15	0.031	0.00541	0.0094	0.0086
18	0.0231	0.00521	0.0094	0.0086
21	0.0198	0.04897	0.0094	0.0086
24	0.0151	0.04897	0.0094	0.0086
27	0.0151	0.04897	0.0094	0.0086
30	0.0151	0.04897	0.0094	0.0086

From the above table, the convergence calculation for the iteration 30 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the convergence measurements of the proposed EMONS-PIM varies from 0.3365 to 0.0086 where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (0.24 to 0.0151), (0.29 to 0.048) and (0.315 to 0.0094). According to this calculation the accomplished results are better for the proposed EMONS-PIM when compared with the earlier methods.

5.2.4 Energy Consumption Calculations for varying iterations:

In this segment the energy consumption calculation of the AntLion, PSO-MSQPA, MLGS-PIM and the proposed EMONS-PIM process is calculated for varying iteration such as 10, 20 and 30. Figure 22, 23 and 24 illustrates the sum rate calculations which are involved in the PIM process and as well its measures are analyzed in table 19, 20 and 21.

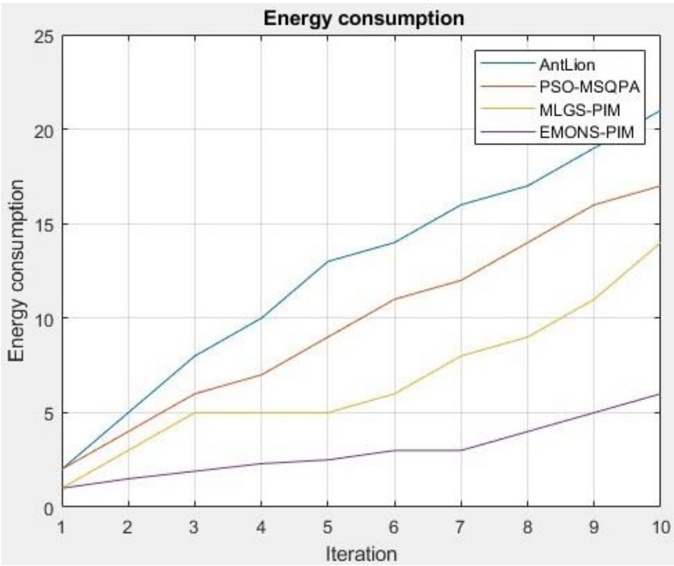

Fig. 22 – Energy Consumption Calculation for Iteration 10

Figure 22 denotes the output of energy consumption for the iteration of 10 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. The core idea of the proposed method is to reduce the energy consumption so that it can able to achieve overall best performance when compared with the earlier methods. The numerical analysis of the energy consumption calculation for 10 iteration counts is given in table 19.

Table 19 - Energy Consumption Value Analysis for Iteration 10

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
1	2	2	1	1
2	5	4	3	1.5
3	8	6	5	1.9
4	10	7	5	2.3
5	13	9	5	2.5
6	14	11	6	3
7	16	12	8	3
8	17	14	9	4
9	19	16	11	5
10	21	17	14	6

From the above table, the energy consumption calculation for the iteration 10 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the energy consumption measurements of the proposed EMONS-PIM varies from 1 to 6% and where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (2 to 21%), (2 to 17%) and (1 to 14%) respectively. From this value analysis it is proven that the proposed EMONS-PIM produce lower energy consumption when compared with the earlier methods and it is achieved with the help of the novel energy consumption reduction process and optimal nozzle section method.

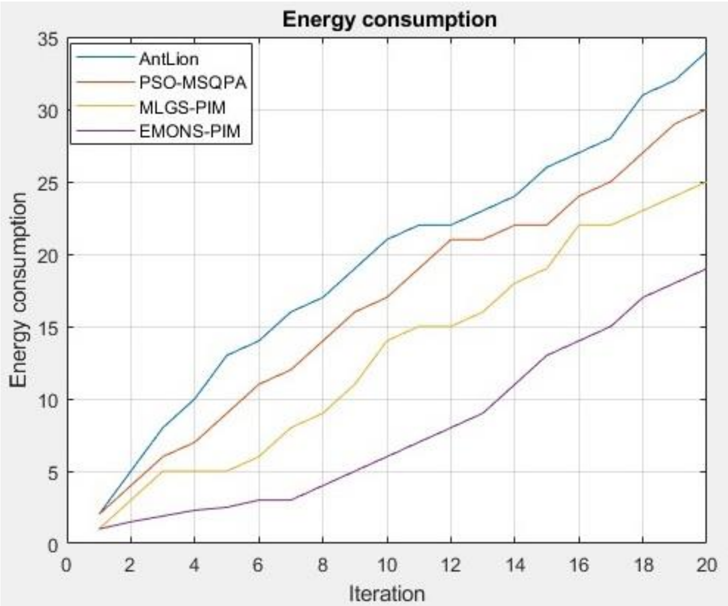

Fig. 23 – Energy Consumption Calculation for Iteration 20

Figure 23 denotes the output of energy consumption for the iteration of 20 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. In the proposed EMONS-PIM, energy consumption reduction is the core idea so that it can able to achieve minimum energy consumption when compared with the earlier researches. The numerical analysis of the energy consumption calculation for 20 iteration counts is given in table 20.

Table 20 - Energy Consumption Value Analysis for Iteration 20

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
2	5	4	3	1.5
4	10	7	5	2.3
6	14	11	6	3
8	17	14	9	4
10	21	17	14	6
12	22	21	15	8
14	24	22	18	11
16	27	24	22	14
18	31	27	23	17
20	34	30	25	19

From the above table, the energy consumption calculation for the iteration 20 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the energy consumption measurements of the proposed EMONS-PIM varies from 1.5 to 19 % and where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (5 to 34%), (4 to 30%) and (3 to 25%) respectively. This analysis shows that the proposed EMONS-PIM achieve minimum energy consumption when compared with the earlier methods.

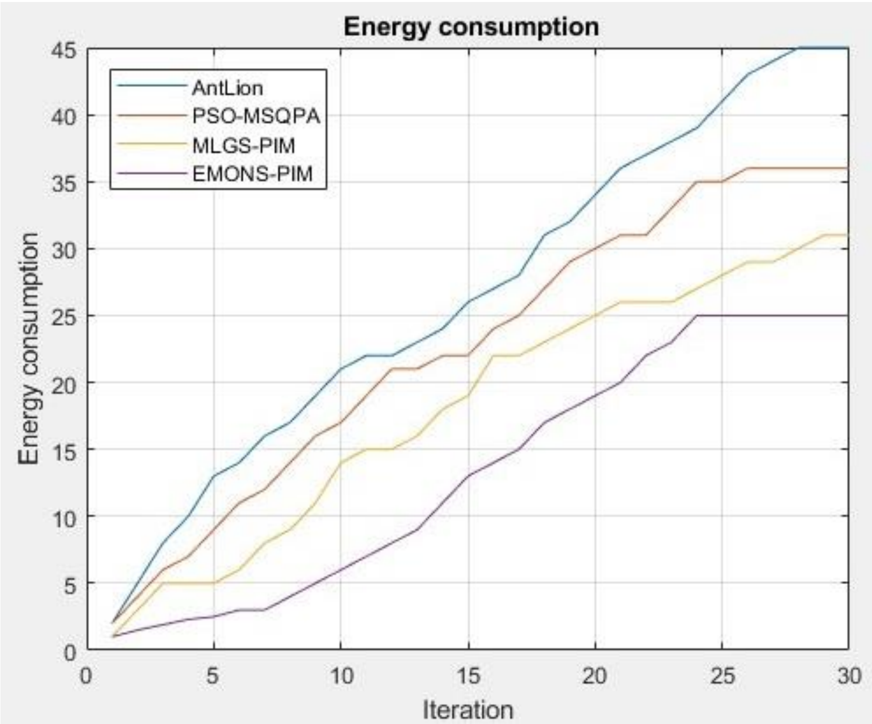

Fig. 24 – Energy Consumption Calculation for Iteration 30

Figure 24 denotes the output of energy consumption for the iteration of 30 counts and the calculations are carried out for the methods like AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. In terms of iteration counts of 30 the proposed EMONS-PIM produced lower energy consumption when compared with the earlier methods which is achieved by concentrating mainly on energy consumption reduction. The numerical analysis of the energy consumption calculation for 30 iteration counts is given in table 21.

Table 21 - Energy Consumption Value Analysis for Iteration 30

Iteration	AntLion	PSO-MSQPA	MLGS-PIM	EMONS-PIM
3	8	6	5	1.9
6	14	11	6	3
9	19	16	11	5
12	22	21	15	8
15	26	22	19	13
18	31	27	23	17
21	36	31	26	20
24	39	35	27	25
27	44	36	29	25
30	45	36	31	25

From the above table, the energy consumption calculation for the iteration 30 counts are calculated for the methods such as AntLion, PSO-MSQPA, MLGS-PIM and proposed EMONS-PIM process. From the table the energy consumption measurements of the proposed EMONS-PIM varies from 1.9 to 25 % and where the comparison methods results are like AntLion, PSO-MSQPA and MLGS-PIM varies from (8 to 45%), (6 to 36%) and (5 to 31) respectively. This results proves that the proposed EMONS-PIM achieve minimum energy consumption when compared with the earlier methods.

6. Conclusion

In this research work, to achieve effective end results in the plastic injection molding (PIM) process the concept of energy monitoring and optimized nozzle section is concentrated and that the energy consumption during the PIM process is greatly reduced and as well the production of the end products becomes more cost effective. Energy consumption is achieved by concentrating on the process parameters such as melting and molding temperature, holding and cooling time, screw rotational speed and nozzle temperature. Mainly by monitoring the cooling time and nozzle temperature the consumption of energy is reduced in the process. On the other hand nozzle section is performed using P20 mold steel to improve the performance of the end results. The simulation experimentation are performed in the software's such as CATIA and MATLAB. In MATLAB the process of energy consumption reduction is concentrated and the parameters which are considered for the process of simulation analysis are sum rate, bit error rate, convergence plot and energy consumption. The materials which are considered in the PIM process are thermoplastic polystyrene, thermoplastic acrylonitrile butadiene styrene and thermoplastic polyvinyl chloride. From the comparative analysis with the earlier researches AntLion Optimization, PSO-MSQPA and MLGS-PIM the proposed EMONS-PIM achieves lower sum rate, lower bit error rate, higher convergence plot and lower energy consumption.

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