Full Paper

DESIGN MODIFICATIONS OF GAS COOKER BURNER FOR OPTIMAL THERMAL EFFICIENCY

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ABSTRACT

Design modification of gas cooker burner for domestic cooking is highly important to enhance acceptability of gas cooking facility globally. Typical material of existing burner was modified by increasing its thickness and also by changing the material of the product from mild steel to galvanize steel to eradicate corrosion at minimum cost. A progressive combination die coupled with drilling fixture for the production of burner were designed, manufactured and evaluated. The die and fixture were used for blanking, piercing and forming of four different burners of port sizes: 2.0, 2.5, 3.0 and 3.5 mm. The most effective burner port size was determined using response surface 3D to generate curves between cooking period, burner head temperature and food cooking temperature against port sizes. Uni-axial compressive test was carried out on cooked rice and beans to investigate their rheological properties. The rice and beans cooking temperatures were found to be: 170 and 180; 150 and 165; 140 and 160; 140 and 160 °C for 2.0, 2.5, 3.0 and 3.5 mm burner port sizes respectively. These results have shown that, burner port size of 2.0 mm exhibited optimum thermal efficiency than any other port sizes. The poison ratios of cooked rice and beans were found to be: 0.25, 0.28, 0.30 and 0.35, 0.23, 0.26, 0.28 and 0.31 for 2.0, 2.5, 3.0 and 3.5 mm burner port sizes respectively. Likewise, the poison ratios of cooked beans were measured to be: for 2.0, 2.5, 3.0 and 3.5 mm burner port sizes, respectively.

KEYWORDS: *Progressive combinations die, press tool, material utility percentage, forming and stripping forces. rheological properties.*

1. INTRODUCTION

Fossil fuels are thought of as cornerstones of our modern age. They generate our electricity, heat homes in temperate countries, fuel our cars, and even form plastics from which many of our modern utensils are made. More so, fossil fuels have played key roles for hundreds of years of our history, driving our transition from a primitive and pre-industrial society to one capable of both encircling this world and reaching beyond (Energy Aware Organization, 2006). Its history begins nearly three centuries ago. Before its exploration, wood and animal fats were common fuels, used primarily for cooking and heating. Fossil fuel originated in the late 18th century, they were formed from the remains of tiny sea plants and animals that died millions of years ago. Over time these organic debris sank into the bottom of the oceans and were buried by thousands of feet of sand and sediment, which turned into sedimentary rock. As the layers increased, they were subjected to high temperature and pressure. The heat and pressure eventually changed the remains into petroleum.

Petroleum is classified as a nonrenewable energy source, because it is depleting and irreversible. Today, we drill through the layer of sedimentary rock to reach the rock formations that contain oil and gas deposits. The crude oil is a liquid fuel mixture of hydrocarbons consisting roughly six parts of carbon and one of hydrogen, with some impurities such as salt sulphur, oxygen, metals and nitrogen. Refining of crude oil is a process in which mixture is heated in a vacuum to 600 °C by injecting superheated steam and pumped through the bottom of a vertical distillation column. As the vapour rises up the column, separation occurs by cooling. The column has trays at different heights with holes. Hence, the cooled fractions with different boiling points liquefied, collected and drained off. The principal products with their corresponding boiling points, are liquefied petroleum gas (LPG) (20 °C), petrol (70 °C), naphtha (40 °C), diesel (200 °C), kerosene and jet fuel (120 °C), lubricant (300 °C), and furnace oil (370 °C). Solid petroleum coke will be collected after liquid fractions were drained (USDE, 2003; GEPI, 2014). LPG consists of propane, propylene, butane, and butylenes. The product used for domestic heating is composed primarily of propane. LPG has two origins: 60% is recovered during the extraction of natural gas and oil from the earth, and the remaining 40% is produced during the refining of crude oil. LPG can be classified under three major grades; commercial-grade butane, engine fuel-grade propane and the commercial-grade butane. It is heavier than air, and liquefies under pressure, which is an added advantage for its haulage. It is generally use as household cooking gas, internal combustion engine fueling, furnace, oven and refrigerant. More than 4 million vehicles are estimated to be powered by LPG in the world. Different improvements had been made in gas cooking from time to time overcoming various challenges. The domestic device with which gas cooking can be achieved is the gas stove/cooker. It refers to as a kitchen appliance that can be used either to generate warmth during cooking (Howell et al., 1996). Gas cooker became a huge commercial success with some 90,000 units sold in the last 30 years, as reported by Gotrinity (2012). In Nigeria, most of this very important energy source is often subjected to flaring, where adequate storage facilities and pipelines were not provided (LPG Exceptional energy, 2012). The Information Age (1999) reported that James Sharp in Northampton, England, was first engineer that patented a gas stove in 1826 and opened a gas stove factory in 1836. More so, during London world fair in 1851, this company exhibited a gas stove, but this invention was not commercialized till 1880s, due to delay in gas pipeline installation. Travis, 1998 reported that, gas stove of enamel wares production started 1910 to eliminate corrosion and for easy cleaning. A high-end gas stove called the AGA cooker was invented in

1922 by Swedish Nobel prize winner. It is considered to be the most efficient design, despite the heavy price tag (Merriman, 2011). Gas stoves had been modified to certain extent by eliminating burner corrosion, through the use of non-metallic materials such bronze, brass, copper and zinc (Hardesty and Weinberg, 1974; Muthukumar, 2011; Michelle 2011). Other modifications were chrome plating of burners, cylinder cum burner design, and burner tripod stand for more air mixture to enhance combustion (Sathe et al., 1990; Zhang, 1997; Worgas, 2011). Even though gas stove had been in existence for years there are still various researches going on to improve its performance efficiency and to reduce emissions (Nelson, 1991; USEPA, 1999; Ashok, 2009).

In Nigeria, there are very few companies that embark on the production of LPG cooker burners such as Nigeria Gas Cylinder, Ijoku Ibadan and Midland Gas Cylinder Abeokuta (formerly located at Isolo Lagos). With the rapid growth in the technological development of our country and in collaboration with World Bank finance project, the laying of gas pipelines has commenced. This necessitated for design modification of exiting gas burner to enhance thermal efficiency and eliminate the incomplete combustion, which can result to environmental pollution. Furthermore, it was observed during preliminary survey that replacing the LPG gas burner was an expensive task and there was limited production, since most cookers are foreign products. This factor was the major reason, why many people could not embark on the use of LPG cooker. Therefore, the objective of this study was to modify the existing gas burner, by varying port sizes (circumferential pierced holes) for gas flaming to determine the best size that will support optimum thermal efficiency. Furthermore, this innovation will increase demand of LPG cooker that will eventually increase utility of LPG. More importantly, it will support generation of court-yard industries and mass production of LPG cookers at minimal cost to meet the crucial need of our society at large.

2. MATERIALS AND METHODS

The existing gas burner sample Fig.1 was obtained from Oshodi Market, in Lagos, Nigeria, of 3.0 mm port size. Adequate measurements of its dimensions were taken to avoid errors. The galvanized sheet was of 1.5 mm thickness was selected for the modify burner to replace the existing gas burner made from mild steel plate to eliminate corrosion. The blank profile was generated using Eq. (1) depicted below to be produced from the strip profile dimensions of 115 x 1240 mm. The material utility percentage was evaluated. Likewise scrap percentage was reduced to the minimal by adopting design procedures of Hinman (1950). The operational parameters of a Single stroke mechanical press of 25 Ton capacity were taken, such as its day light, short height, shoe holder diameter and bed slotted grove dimensions. A combination die for blanking and forming operation was designed and fabricated as described below.

2.2. Design Calculations

2.2.1. Determination of burner blank size.

The burner blank diameter was determined by making use of an existing old burner shown as Fig.1 shown above. For standardization purposes, all dimensions of the old burner were taken with the use of vernier calliper and radius gauge. The blank diameter was generated using Eq. (1)

$$D = a + \left(R_1 + q_1 + \frac{s}{2}\right)\frac{\pi\alpha_1}{180} + b + \left(R_2 + q_2 + \frac{s}{2}\right)\frac{\pi\alpha_2}{180} + c \quad (1)$$

source: ASTME (1959).

Where,

D = Diameter of blank

a = c = height of burner = 10.0 mm

b = Length of burner base = 80.0 mm

R_1= R_2 = Radius of curvature = 6 mm

s = Thickness of material = 1.5 mm

q_1= q_2 = Coefficient of material = 0.6 mm

$\alpha_1 = \alpha_2$ = angle of curvature to the horizontal plane = 90^0

The diameter of the burner calculated from the equation = 110 mm

2.2.2. Determination of blanking force

The blanking force was determined using Eq. (2) as shown below:

$$P = Lts \quad (2)$$

Source: Frank et al, (1965) and Morakinyo (2009)

Where,

L = forming circumference $= \pi D =$ 345.71 mm

t = plate thickness = 1.5 mm

s = shear strength of steel = 350 MPa = 350 M N/m ^{2} = 350 N/mm^2 (Khurmi and Gupta, 2005; Morakinyo, 2009).

Therefore, the blanking force was calculated to be 181,497 N/10 = 18,149 kg = 18.2 tons

Fig. 1: Exiting Old Gas Burner
Scource: Oshodi market, Lagos

Power press of 25 tonnes was recommended by considering factor of safety of 35% for steel material (Khurmi and Guptal, 2006). The available power press at IFECO, Ketu, Lagos was preferred having these following configurations: Stroke of 80 mm, Adjustable heights facility of 75 mm, short height 150 mm, the day light 220 mm and the shank/ shoe holder was found to be 50 mm diameter with height of 60 mm.

2.3. Determination of ejector stripping force

The ejector stripping force was determined to facilitate appropriate selection of compression spring load for an effective ejection of both blank and formed gas burner after piercing operation. Frank et al. (1965) reported the collective submission of representatives of die makers and fabricators, that stripping pressure/force vary from 2.5 to 20% of blanking / punching force. Hence, 10% of the calculated blanking force was recommended as stripping force. Therefore, ejector stripping force = 2.5 ton. The corresponding compression spring that has the load capacity of 2.5 ton was selected having these dimensions: SWG 5/0, wire diameter 10.97 mm, free length 170 mm, and allowable stress of 364 MPa (Khurmi and Gupta, 2005).

2.3.1. Determination of forming force

The amount of forming force required for an effective interaction between punch and die was calculated using this mathematical expression shown below as Eq. (3).

$$F = \frac{KLSt^2}{W} \quad (3)$$

Source: Frank et al. (1965).

Where F = Bending force required at one side of the burner (ton)

K = Die opening factor influencing the spring back which varies from 1.2 for a die opening of 16 times metal thickness and above to 1.33 for a die opening of 8 times metal thickness. In this case, die opening was 81.5 mm equal to the outer diameter of old burner, which was more than 16 × 1.5 = 24 mm Therefore, K selected was 1.2.

S = Ultimate tensile strength of tons/in^2.The ultimate tensile strength of steel reported by Frank et al. (1965) was 40 tons/in^2. Blank area = 14.74 in^2

T = metal thickness = 1.5mm = 0.059 in,

W = Die opening = 81.5 mm = 3.33 in.

L = Blank diameter = 110 mm = 4.33 in

$$F = \frac{1.2 \times 4.33\ in \times 40\ tons \times 0.0035\ in^2 \times 14.74}{3.33\ in \times in^2} = 3.33\ \text{tons.}$$

$$\text{Forming force} = 2 \times F + (\text{Blank area} \times 0.15) \quad (4)$$

Source: Frank et al. (1965).

Hence Forming force = 8.87 tons. This can be adequately delivered by selected mechanical powered press of 25-ton capacity.

2.4. Construction of press tools

The production of LPG gas burner for domestic cooking of food produce, involved design and construction of two separate dies, namely: progressive and combination die and blank piercing fixture. In this study, only a progressive combination die will be discussed in details. The progressive combination die was a pillar guided type of 200 mm vertical height. The explosive view of this die is shown in Fig. 2, while working components were listed on Table 1 with their corresponding dimensions.

2.4.1. Description of progressive and combination die

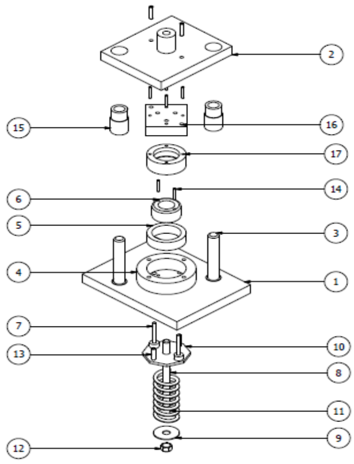
Upper bolster: This was made of low carbon steel of 40 × 270 × 230 (mm). At the centre of it was located a shoe holder with the help of M12 × 60 Allen bolt. Diagonally, two bushes/guides pillar were fixed such that both upper and bottom bolster will be concentric. The bushes were made of high carbon steel with hardness value of 45 HRC.

Die holder: This was made of medium carbon steel of 36 × 120 × 110 (mm). It was located at the bottom of upper bolster guided with two dowel pins for centrality and concentricity in coupled with combine die. It was heat treated to 40 HRC to avoid deformation of combine die.

Combine Die: The combine die was made of tool steel material of θ 110 mm outer and stepped turned to 81.5 mm inner diameter. It was hardened to 60 HRC and tempered to avoid cracking. This was coupled to the die holder with the help of dowel pins and fasteners. This die performed two functions of blanking with outer diameter of 110 mm and while the inner diameter of 81.5 mm was used for forming operation.

Bottom bolster: The bottom bolster was made of low carbon steel of 40 × 360 × 280 (mm). Two guided pillars of θ 30 mm x 195 mm were force fitted at a distance corresponding to centre distance observed on upper bolster. The blanking die was located at the centre of this bolster.

Blanking die: This was made of tool steel material of outer diameter of θ 160 mm and inner diameter of θ 110.25 mm It was hardened and tempered to the hardness value of 60 HRC. It was encasing pressure plate suspended with the help of ejector pins. These ejector pins were guided with spring upper plate, followed by the compression spring, located at the bottom bolster. The compression spring was retained by spring bottom plate with help of stud threaded at centre of the bottom bolster. The height of pressure plate was adjusted through the fastening of hexagonal bolt located below spring bottom plate, until its height was at parallel to blanking die.



PARTS LIST			
S/N	QTY	PART NAME	MATERIAL
1	1	LOWER BOLSTER	Steel
2	1	UPPER BOLSTER	Steel
3	2	PILLAR	Steel
4	1	REVERSED PUNCH	Steel
5	1	PRESSURE PLATE	Steel
6	1	FORMING DIE	Steel
7	2	EJECTOR PIN	Steel
8	1	STUD	Steel
9	1	SPRING UPPER PLATE	Steel
10	1	SPRING LOWER PLATE	Steel
11	1	SPRING	Steel
12	1	Nut	Steel
13	8	Hex Stud-01	Steel
14	6	Hex Stud-02	Steel
15	2	BUSH	Steel
16	1	DIE HOLDER	Steel
17	1	DIE	Steel

Fig. 2: Exploded View of Combination Die for LPG Gas Burner Manufacturing

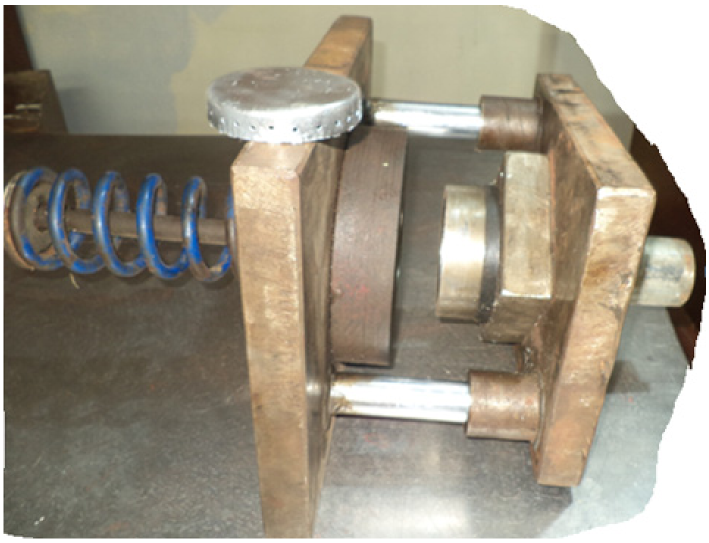


Fig. 3: Progressive and Combination Die with a sample of 2.0 mm Port Size Burner.

2.4.2. Blank piercing fixture

The production of gas cooker burner was done sequentially to reduce the cost of production. After the blanking operation, blanks were loaded inside piercing fixture at rate of five numbers at a time. The piercing fixture consists of blank holder of cylindrical shape, threaded externally to allow the fastened of cover plate that compressed drilling insert dies of different port sizes namely: 2.0, 2.5, 3.0 and 3.5 (mm). This drilling insert was made of tool steel of 10 mm thickness, having 30 holes (ports) at circumferential diameter of 78.0 mm and of equal diameter to blank size. To produce a set of burner of a particular port size, the corresponding insert die was loaded while the same size of drill bit was fitted on pillar drill machine chuck to pierce blank circumferentially. Thereafter, the pierced blanks were returned back to the progressive and combination die for forming operation by adjusting the stroke of mechanical powered press down ward till complete formation of gas burner was produced.

2.5. Performance Evaluation of Burners

The LPG burners produced with varying port sizes (circumferential pierced holes) were used extensively to determine optimum thermal efficiency. Two food items; rice and beans were cooked with individual type of gas burners port sizes: 2.0, 2.5, 3.0 and 3.5 (mm) under the same regulatory gauge pressure of 2.0 Bar. Three dependent cooking variables were considered, namely: cooking period, burner head temperature and rice/beans boiling temperature measured against an independent variable (port size). The interactions of these variables were subjected to response surface 3D XYZ Plot for better interpretation. Finally, textural and rheological properties of both cooked food materials were subjected to uni-axial compression test for thorough investigation.

3. RESULTS AND DISCUSSION

The response surface 3D XYZ plots generated from the experimental data were shown as Fig. 3 to 10. The result indicated that, burner of port size 2.0 mm diameter has the shortest cooking times during the rice and beans cooking. Likewise, it exhibited the highest values of the cooking temperature for both food items. It was observed to be the best burner port size that converted the heat content of LPG as input energy into thermal energy efficiently with maximum cooking temperature. Furthermore, the optimum performance of burner port size 2.0 mm may be attributed to the fact that it has minimum diameter through which the gas atomized effectively which enhances blue flame generation. The performance evaluation data collected for 2.0, 2.5, 3.0, 3,5 mm port size burners were shown as Fig. 4, 5, 6 and 7 response surface diagrams respectively during rice cooking process. From the Fig. 4, the optimum burner head temperature of 92 °C commenced at 15 min and remained constant till the end of cooking period of 40 min, which generated ultimate rice cooking temperature of 170 °C. Considering Fig. 5 of burner port size 2.5 mm, its optimum burner head temperature of 92 °C arrived at 22.5 min and remained steady till the end of 40 min with maximum rice cooking temperature of 150° C. However, burner of 3.0 mm port size commenced its optimum burner head temperature of 92 °C at 35 min out of 40 min to produce rice cooking temperature of 140 °C. Generally, it was observed as burner port sizes increased the burner head and rice cooking temperature decreased. The same trends of observations were obtained during cooking of beans using port size burners of 2.0, 2.5 3.0 and 3.5 mm as demonstrated in Fig. 8, 9, 10 and 11 response surface diagrams. Fig. 8, depicted the performance evaluation diagram of 2.0 mm port size. The maximum burner head temperature of 92 °C occurred at 22 min and increased linearly to 95°C at the shortest period of 50 min during beans cooking with optimum temperature of 180 °C. Hence, in Fig. 9 of 2.5 mm burner port size, the maximum burner head temperature of 92 ° C commenced at 30 min and increased steadily to 93 °C at 55 min of beans cooking with optimum temperature of 165 °C.

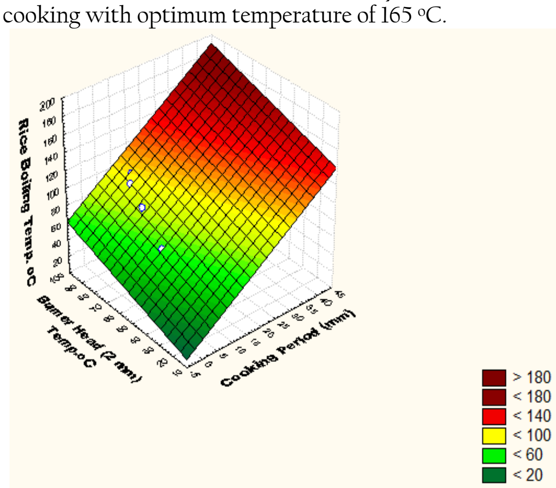


Fig. 4: Thermal Efficiency of 2.0 mm Burner size for Rice Cooking

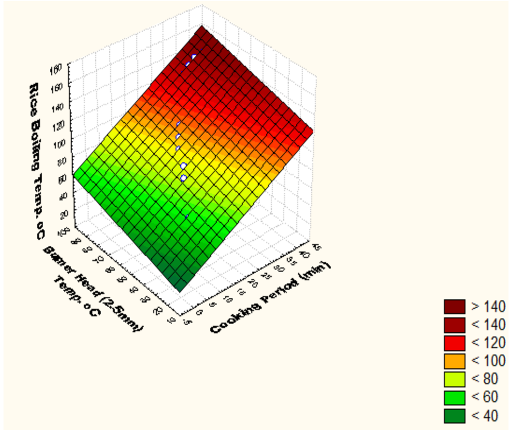


Fig. 5: Thermal Efficiency of 2.5 mm Burner size for Rice Cooking

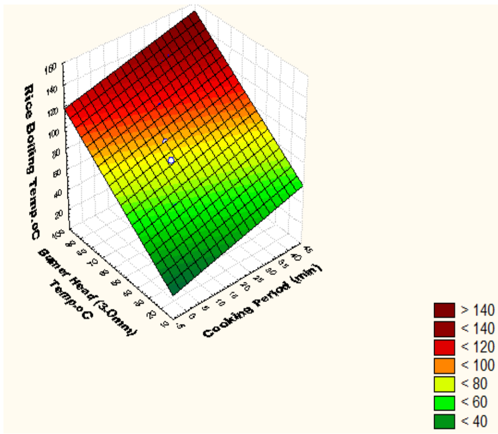


Fig.6: Thermal Efficiency of 3.0 mm Burner size for Rice Cooking

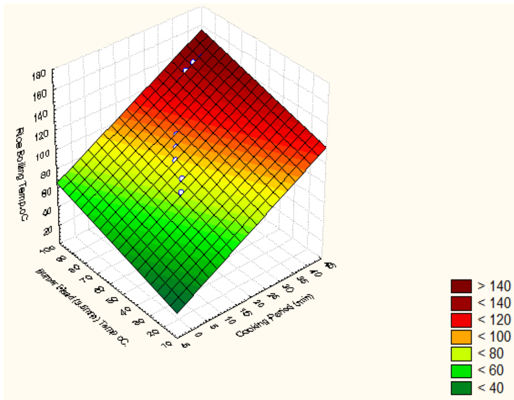


Fig.7: Thermal Efficiency of 3.5 mm Burner size for Rice Cooking

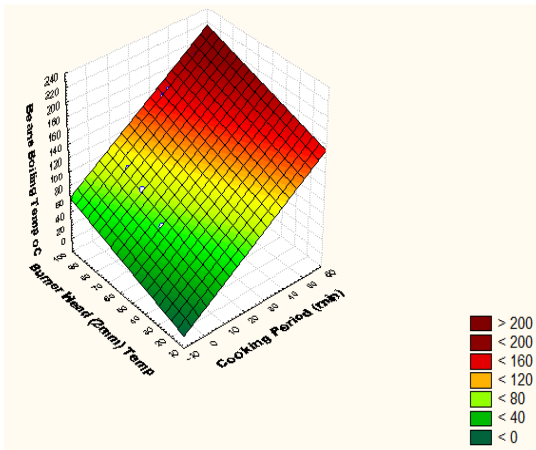


Fig. 8: Thermal Efficiency of 2.0 mm Burner size for Beans Cooking

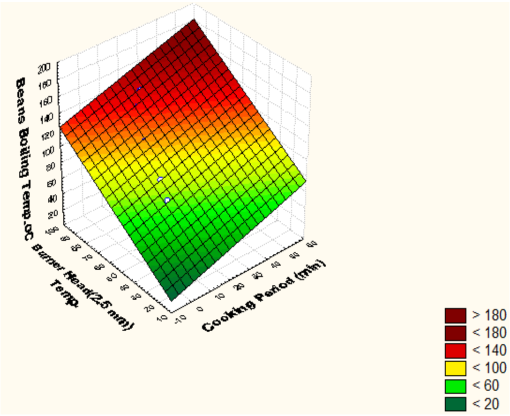


Fig. 9: Thermal Efficiency of 2.5 mm Burner size for Beans Cooking

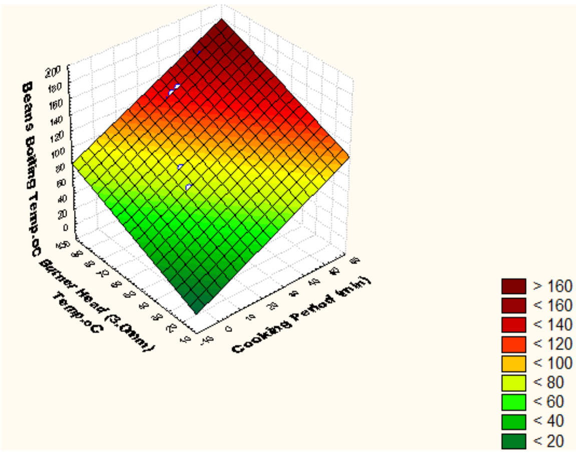


Fig. 10: Thermal Efficiency of 3.0 mm Burner size for Beans Cooking

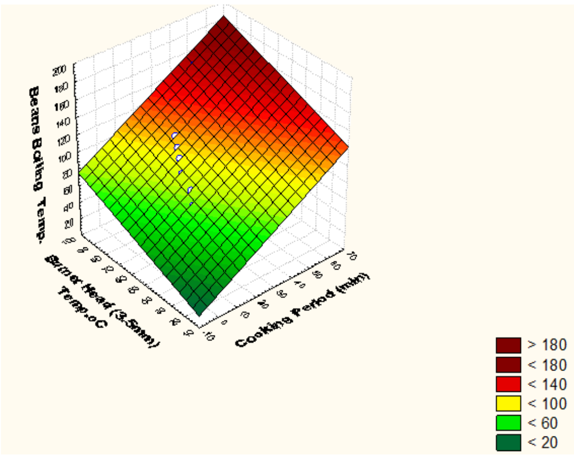


Fig. 11: Thermal Efficiency of 3.5 mm Burner size for Beans Cooking

Considered Fig. 10 of 3.0 mm burner port size, invariably, the maximum burner head temperature of 92 °C occurred at 35 min and remained constant till the end of beans cooking period of 57.5 min with optimum cooking temperature of 160 °C. Finally, Fig. 11 demonstrated performance evaluation of beans cooking on 3.5 mm burner port size, the maximum burner head temperature of 92 °C, commenced at 40 min and remained constant till longer period of 60 min was observed, which generated the optimum temperature of 160 °C. The results shown that during the cooking of rice and beans at separate period, gas burner of port size of 2.0 mm arrived at 92 °C earlier than any other gas burner port size. More importantly, cooking of both food materials were completed at minimum period and at higher temperature with gas burner of port 2.0 mm than remaining gas burner sizes. Since liquefied gas flow rate remain constant during the performance evaluation, it can be deduced that gas burner of 2.0 mm port size has higher thermal efficiency and more timely and economical than others.

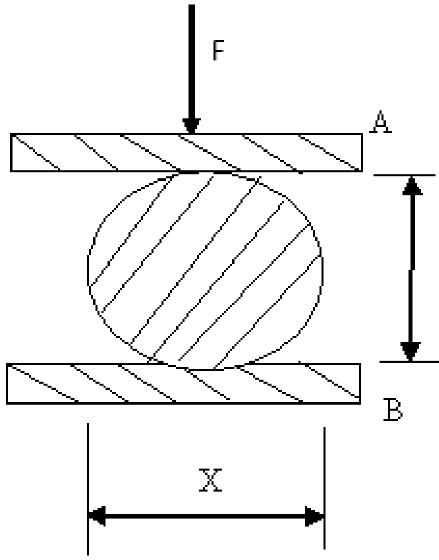


Fig. 12: Uni-axial compression test of Cooked Rice and Beans

Fig. 12, shown below, demonstrated the loading of the cooked food material during uni-axial compression test. Considered Fig. 13, 14, 15 and 16 of poison ratio, shown the axial and lateral strains curves of cooked rice and beans respectively during compression test. The results indicated that rice and beans cooked with 2.0 mm port size burner exhibited maximum values of axial and lateral strains under minimum application of compressive force, while rice cooked with 3.5 mm port size has minimum values of both axial and lateral strains. The poison ratios of cooked rice were calculated as: 0.25, 0.28, 0.30 and 0.35 for 2.0, 2.5, 3.0 and 3.5 mm burner port sizes respectively. Likewise, the poison ratios of cooked beans were also calculated as 0.23, 0.26, 0.28 and 0.31 for 2.0, 2.5, 3.0 and 3.5 mm burner port sizes respectively. These experimental results were compared favourably with other values reported by previous researchers on uni-axial compression test of grains and fruits. Moshsenin (1986) reported that most food materials exhibited poison ratio between: 0.2 to 0.5. The variability in their rheological properties validated differences in burners' thermal energy efficiency. It was also observed during uni-axial compression test, those samples of rice and beans cooked with burner of 2.0 mm port size arrived at their corresponding bio-yield point faster than those sample cooked with other burners. This relationship between the bio-yield point, compressive stress and sterilization were reported by Fellow (2000) and Sirisomboon et al. (2007).

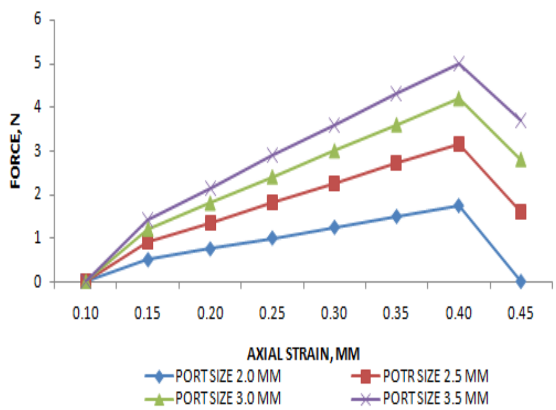


Fig. 13: Axial Strain of Cooked Rice Under Compression Test

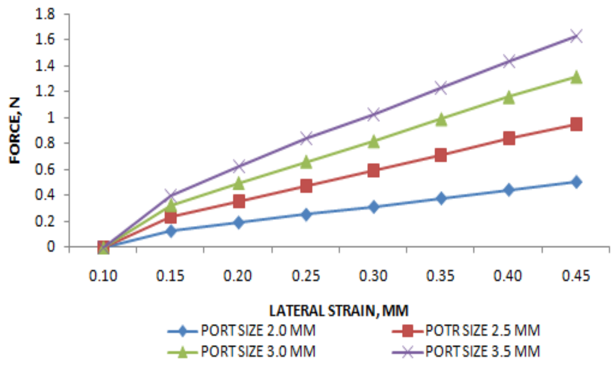


Fig. 14: Lateral Strain of Cooked Rice Under Compression Test

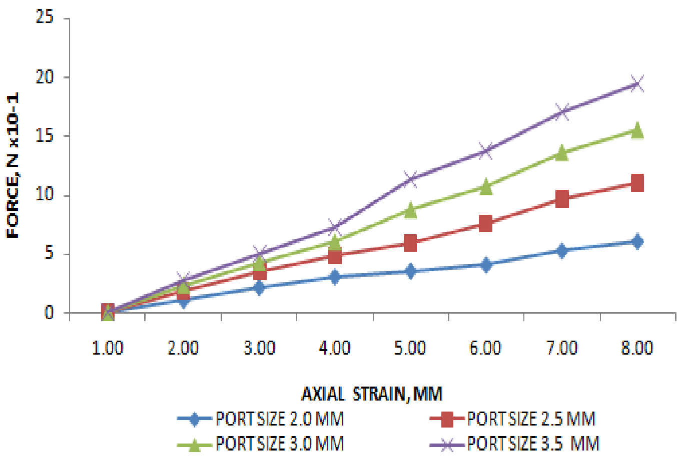


Fig. 15: Axial Strain of Cooked Beans Under Compression Test

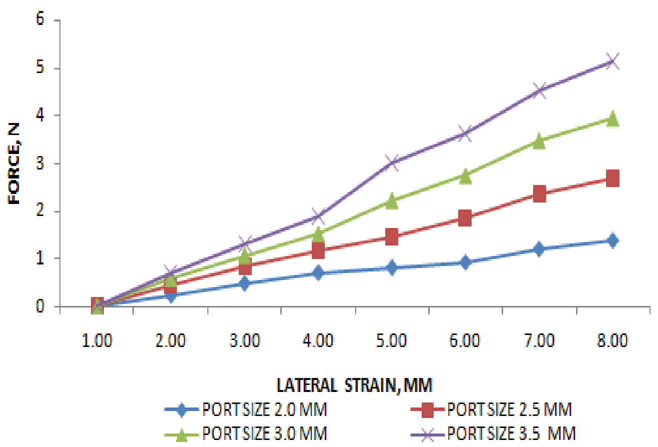


Fig. 16: Lateral Strain of Cooked Beans Under Compression Test

4. CONCLUSIONS

There are many areas in the gas industry where there is a definite need to bridge the gap between fundamental concepts and engineering application. The design of atmospheric gas burners for domestic and commercial appliances requires a judicious balance of characteristics. Knowledge of quantitative effects of all pertinent variables is therefore, necessary to achieve a desired balance in design. When designing a burner for domestic cooking, it is concluded that the use of smaller port sizes for gas burner when low gas supply is needed is advisable. This will enhance lean mixture, effective gas flame propagation and complete combustion to attain greater thermal efficiency. Gas cooker burner design research is a continuing process that involves fundamental concepts, the engineering design and metal forming technology.

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