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# The Performance Study of Alcohol in an Air Gap Ceramic Insulated Diesel Engine with Brass Piston

S Sunil Kumar Reddy[1*], V.Pandurangadu[2], M.Venkat Rao[3]

[1] Associate Professor, Mechanical Department, N.B.K.R.I.S.T., Vidyanagar -524 413, Nellore (Dt.), A.P., INDIA
[2] Professor,Department of Mechanical Engineering, JNT University, Anantapur, A.P., INDIA
[3] Professor, Department of Mechanical Engineering, N.B.K.R.I.S.T., Vidyanagar -524 413, Nellore (Dt.), A.P., INDIA

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**Abstract**

Now a day it is becoming a challenge for the researchers to find a suitable alternative for diesel and to conserve fossil fuels, which are going to drain in the near future. These factors are to be considered for the invention of new designs of engines. This plays a major role for the researchers in the engine design. The alternative fuel selected must be a renewable, environmentally friendly liquid fuel, and it should provide less pollutant emissions. As ours is an agricultural country, the production of sugar cane is more and this plays a vital part in the production of alcohols which is a very good substitute for diesel. But with the high self-ignition temperature and low latent heat, it becomes difficult to burn alcohol in the existing diesel engines at the available compression ratios and injection pressures. But these have a peculiar property, burning at the elevated temperatures in the combustion chamber. Hence, in the present work, a ceramic insulated diesel engine is developed with an air gap between piston and skirt. This retains the heat in the combustion chamber, makes the combustion complete and further improves the thermal efficiency of the engine with a reduction in the emissions. The heat retaining capacity of the engine mainly depends on the piston material. Therefore, an attempt is made, in the present work, to study the performance and the emission characteristics of the engine with brass piston. Further, the turbulence in the combustion chamber provides the homogeneous mixture formation and improves the combustion quality. So the performance parameters of the engine are tested with brass piston insert and with twelve grooves. Among the various piston inserts tested, the brass insert with 12 number of grooves is identified as the best in terms of performance and emissions. However, in the present experimental work, the major problems acknowledged are the drop in volumetric efficiency and lubricating oil descent with the higher prevailing temperatures in the chamber. However, these problems can be overcome by turbocharging and with the development of new lubricating oils.



**Keywords:** *Ceramic Engines, Air Gap Insulation, Low Heat Rejection Engine, PSZ, Alcohol, Brass Piston.*

## 1. Introduction

Diesel engines have major applications in the transportation sector which plays a key role in India's economy. But the diesel fuel is depleting at a fast rate and it causes pollution. So an alternative fuel is required. Hence, the alternative fuel selected must be replenishable, cheap and easily available. In our country, the majority of people lives in villages and their main occupation is agriculture. Further, if farmers prepare this alternate fuel, they will become independent for their needs. As India has about 100 million hectares of waste land, farmers can utilize this land which will become an untapped resource for India. Now a day farmers are producing various types of crops that are useful for the production of vegetable oils. Among all the fuels, alcohols are the best which will be the by-product in the production of sugar. Implementation of alcohol as a fuel in I.C. engines in India will lead to many advantages like greening the waste land, supporting the agricultural sector, rural economy, and reducing the dependence on import crude oil and decreasing pollution. But alcohols have a high self-ignition temperature and a low latent heat which makes the burning of alcohols in diesel engines difficult at the available compression ratios and injection pressures.

Based on the available literature, it is observed that much amount of work has been done on the utilization of alcohol with diesel in the form of a blend. But with blends, the amount of fuel utilized is less and so the farmers will be short on their energy needs. If alcohol is used directly in the diesel engine without a blend with diesel, it will fulfill the requirements. But due to its properties, the combustion of alcohols is possible at the elevated temperatures in the combustion chamber. So in the present work, a ceramic engine is developed with the insulation of the combustion chamber [2, 3 and 4] with ceramics. Ceramics have a higher thermal durability and a lower thermal conductivity that controls the temperature distribution and heat flow in the structure. A lower heat rejection from the combustion

* Corresponding author. e-mail: mohdhn@yahoo.com.

chamber through thermally insulated components increases the available energy. This would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could also be utilized.

A major breakthrough in the technology of diesel engines has been achieved by the innovative work done by Kamo and Bryzik. R.Kamo *et al.* [6] conducted experiments with 0.13 mm thick thermal barrier coating of PSZ for the piston and cylinder head and 0.5 mm thick coating for cylinder liner. They observed, in the experiment, a higher premix, lower diffusion combustion, a reduction heat transfer loss, a higher heat release in the combustion chamber with 5 to 6 percent improvement in fuel efficiency at all the loads and speeds. T.Morel *et al.* [5] attained higher thermal efficiency at all loads for both heavy and light engines with the various level of insulation at constant peak pressure and A/F ratio. An eight percent improvement in the brake thermal efficiency was observed. Heat rejection was reported to be decreased while exhaust temperature was increased. S.H.Chan and K.A.Khor *et al.* [8] reported 4 to 7 % improvement in fuel consumption in single cylinder DI diesel engine. This was accomplished by using a constant air flow rate with boosting pressure with 1 mm thick PSZ coating to the cylinder head face and the valve heads by placing a short solid PSZ cylinder liner in the area above the piston rings and heat insulated steel piston. Nagalingam *et al.* [12] converted the four stroke diesel engine into LHR engine with the insulation of the components and conducted the experiments with alcohol and concluded that the performance of the engine with the insulation was increased and the emissions were reduced considerably. Y.Miyairi *et al.* [7] reported a reduction in BSFC by 7% under naturally aspirated conditions in single cylinder DI diesel engine. In this attempt, the fuel injection pressure and the amount of fuel injected was kept constant and the cylinder liner was water cooled. The chamber walls are insulated with PSZ. Murthy PVK *et al.* [9] reported the results of their investigations on LHR diesel engine with 3 mm air gap between piston skirt and insert with Nimonic alloy crown. They revealed that the performance was deteriorated at the available injection timing and pressure. At peak loads, the BSFC was decreased by 12 percent and smoke levels by 16 percent, but NOx levels were increased by 34% with an injection timing of 32 $^0$bTDC. Wallace *et al.* [11] have reported the use of a thermal barrier piston in the adiabatic engine and developed the temperature distribution analysis and reported that the piston top temperature were higher by around 400$^0$C for the thermal barrier pistons.

From the literature, it is observed that a great amount of heat is lost through the piston. Hence, in the present work for the reduction of heat through the piston, thereby increasing the efficiency, an attempt is made with brass piston crown and air gap between piston skirt and crown. The brass crown is also as same as the size of the original piston and can be interchangeable [9, 10]. Similarly with the turbulence in the chamber, a homogeneous mixture can be formed and thus an increase in the efficiency becomes possible. Therefore, in this work twelve numbers of grooves are made on the brass piston and is used for the testing.

## 2. Objective

The main objective of the present investigation is to figure out the suitability of the insulated engine for alcohol. The experiment has the following phases:

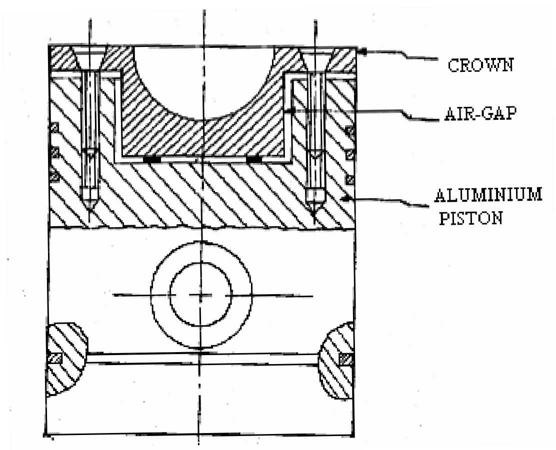
1. Conversion of the conventional diesel engine into insulated engine
2. Investigations with different piston inserts
3. Results and discussions

### *2.1. Conversion of the Conventional Diesel Engine into Insulated Engine*

The important and most complicated part of the experimental work is the conversion of the normal diesel engine into an insulated engine with the insulation of the various components of the engine. So the engine components are insulated first. The detailed method of insulation is given below.

#### *2.1.1. Piston Insulation*

With the available literature, an air gap of 2 mm is optimized between the piston crown and skirt. This air gap retains the heat in the chamber. Figure 1 shows the line diagram and photographic view of the piston crown used in the experiment.




(a) Line diagram

(b) Photographic view of aluminum crown

**Figure 1.** Air gap insulated Aluminum crown

*2.1.2. Cylinder Liner Insulation*

As the piston is moving in the cylinder, the air gap insulation of 2 mm is provided on the outer surface of the liner. This insulation reduces the heat transfer to the cooling medium.

*2.1.3. Cylinder Head and Valve Insulation*

The ceramics have better heat and wear resistant characteristics, which retains the heat in the combustion chamber, improves the combustion efficiency, and reduces the pollutant emissions. For the present experiment, ceramic is chosen as the insulating material because of its low density, high thermal stability, and stability in severe chemical environment, its requiring low thermal conductivity and its favorable strength as well as its creepy behavior. Ceramic coating is a simpler method of insulation for cylinder head and valves compared to other methods. The method of coating the Partially Stabilized Zirconia (PSZ) on the engine components are explained below.

Zirconia is usually produced from the zircon ($ZrSiO_4$). For the production of the zirconia, the zircon is to be added with NaOH and HCl, so that the zircon is converted to zirconyl chloride. The reactions are as follows:

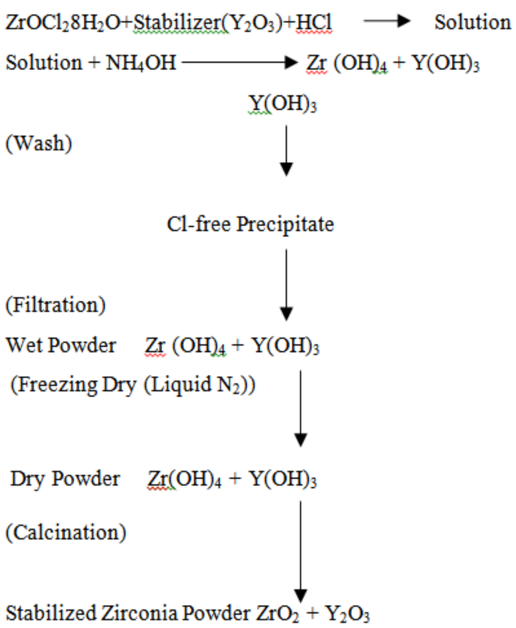



**Figure 3.** Photographic view of plain brass piston (BP)

With the available PSZ powder, the coating will be done on the cylinder head and valve surfaces. In coating, the following processes are involved:

1. Pre-cleaning and pre-machining of the cylinder head and valve surfaces to remove rust, scale, paint, etc.
2. Coating of the PSZ powder on the component surfaces using plasma spraying technique up to the required thickness.
3. Final finishing operations, like grinding, lapping, polishing and cleaning.

**Figure 2**. PSZ coated cylinder head and valves

With the above specified methods, the cylinder head and valves bottom surfaces are machined to a depth of 0.5 mm and further insulated by coating the area exposed to the combustion with PSZ. The surface was then sand blasted to form innumerable pores. This coating prevents the heat flow through the cylinder head and valves. The PSZ coated cylinder head and valves are as shown in Figure 2 above. All these insulated parts, described above, are interchangeable with the standard engine parts.

*2.2. Investigations with Different Piston Inserts*

In the present work, for the reduction of the heat transfer from piston to the skirt, a piston is designed similar to that of the original aluminum piston which retains the heat in the combustion chamber and preheats the incoming charge. Further, for the good turbulence in the combustion chamber, an attempt is made with twelve numbers of grooves on the brass crown piston. The size and the shape of the groove are selected in such a way that a maximum number of grooves will be generated on the brass piston with the available technology. This brass crown piston is further knurled to increase its surface area to facilitate a better heat transfer from the gases to the brass crown. The brass pistons, tried in the work, are shown in Figures 3 and 4, and the same is compared with aluminum piston.

**Figure 4.** Photographic view of Brass crown piston crown with twelve grooves (BP12)

*2.3. Results and Discussions*

The experimental study is carried out on a single cylinder, water-cooled 3.68 KW Kirloskar ceramic coated diesel engines by changing piston crowns. First, the engine is operated with an aluminum piston by the diesel fuel. Then, it is further operated with alcohol with an aluminum piston and then with brass inserts. Both performances are mentioned in the graphs. If the engine is operated at the normal injection pressure, more alcohol will be injected into the combustion chamber due to its lower viscosity. Owing to its high latent heat of vaporization, it cools the engine combustion chamber. So for the present work the fuel injection pressure is reduced to 165 bars. All the tests are conducted at the rated speed of 1500 rpm.

The concentration of smoke is measured by Bosch smoke meter; UHC and NOx are measured with non-dispersive infrared (NDIR) AVL exhaust gas analyzer. The air suction rate and the exhaust air flow rates were measured with the help of an air box method. Temperatures at the inlet and exhaust valves are monitored using Nickel-Nickel Chromium thermocouples. The time taken to consume 20 cc of fuel was noted down using a digital stop watch. Engine RPM is measured with an electro-magnetic pick up in conjunction with a digital indicator of AQUTAH make. The diesel fuel and alcohol fuel are subjected to performance and emission tests on the engine with various piston inserts and the analysis of these results are as follows. The experimental set up used in the present work is shown in Figure 5.

**Figure 5.** Photographic view of Insulated Engine Experimental set up

*2.3.1. Exhaust Gas Temperature*

With the lower thermal conductivity of the PSZ, it holds the heat generated in the combustion chamber. Further, the brass piston restricts the heat flow through the piston. This increases the combustion efficiency and exhaust gas temperature, which makes the ignition of alcohol positive. Figure 6 shows the variation of exhaust gas temperature for three different types of pistons in an insulated engine. The exhaust gas temperature for brass piston is 560$^0$C and for aluminum it is 510$^0$C at full load with diesel. The exhaust gas temperatures of diesel fuel and alcohol with aluminum piston are closer. With the higher prevailing temperatures in the chamber, the complete combustion of diesel has taken place. The complete burning of alcohol in the chamber is attributed to the oxygen content in alcohol and the insulated environment in the chamber. The turbulence provided by the grooves on the piston increases the exhaust gas temperature. So the insulated engine with BP12 shows maximum temperature at rated loads, which is 2.12% more than BP. The increased temperature inside the engine cylinder will increase the entropy and, in turn, will reduce the efficiency slightly, but it is controlled by the higher latent heat of alcohol. Further, this heat is rejected to the exhaust. This high temperature exhaust gas energy can be recovered by a turbo compounding system.

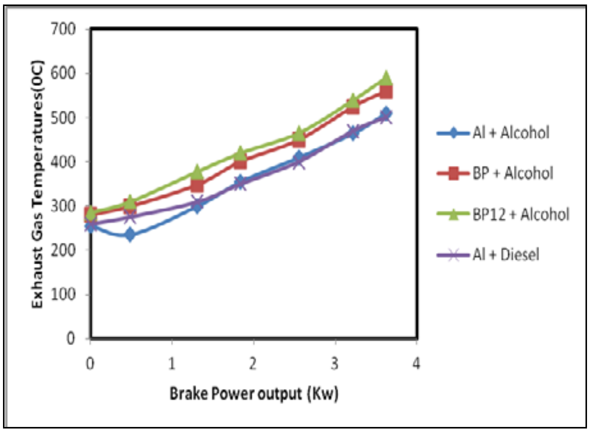



**Figure 6**. Comparison of Exhaust gas temperature with power output

*2.3.2. Brake Thermal Efficiency*

Figure 7 shows the variation of brake thermal efficiency of the ceramic insulated engine with the power output for various piston inserts. With ceramic insulation, the heat flow is restricted to the cooling system and these further increases with the brass pistons, air gap between piston and skirt, and with the grooves on the brass piston. As the brass crown piston acts as a good heat reservoir, it maintains the heat in the chamber and further combustion completes. The efficiency with brass pistons is comparatively more than the aluminum piston. So the brake thermal efficiency of BP12 is increased by about 1.58% compared to BP at the rated loads. The efficiency of alcohol with the aluminum piston is slightly more than the diesel. This is endorsed to the alcohols fuel injection pressure and oxygen content in the alcohol.

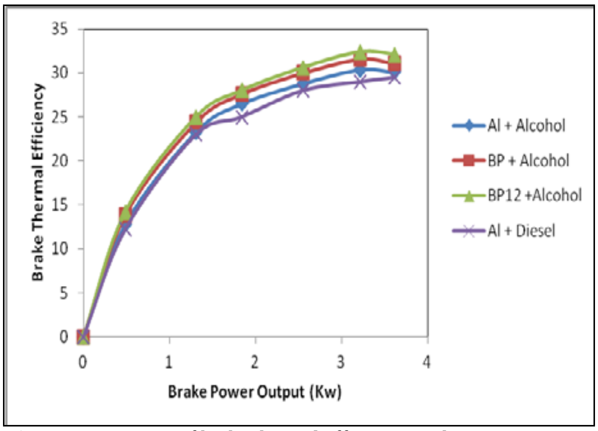



**Figure 7.** Variation of brake thermal efficiency with power output

*2.3.3. Volumetric Efficiency*

Figure 8 depicts the volumetric efficiency variation for various piston materials. With the basic properties of brass material, it absorbs the heat during the combustion process and the same heat is given back to the incoming charge in the suction stroke. This enhances the temperature of the inward charge and makes the combustion complete. The higher temperatures in the combustion chamber, with the brass pistons, trims down the density of the inward charge, drops the volumetric efficiency, and plunges the power output. This heat depends on the formation of homogeneous mixture and further turbulence in the combustion chamber. The amount of heat retaining capacity varies for different materials.

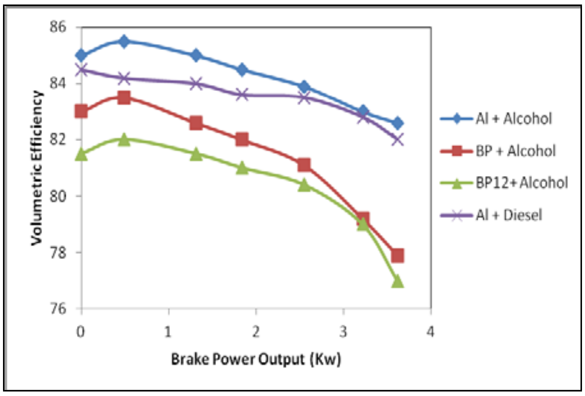



**Figure 8.** Variation of Volumetric Efficiency with Power output

The aluminum piston volumetric efficiency fluctuates from 85% at no load to 82% at full load. This fall in the volumetric efficiency varies with the heat in the combustion chamber. So for BP the absolute drop is 3.35% compared to the aluminum piston at the rated load, and the fall in the volumetric efficiency with BP12 is peak and is about 1% compared to BP. This reduction of volumetric efficiency is to be compensated with turbocharging.

*2.3.4. Smoke Density*

With the inferior operating temperatures and due to the lack of oxygen, the combustion will be incomplete in the combustion chamber and this may cause smoke in the exhaust. But in the present work the brass piston holds the heat in the chamber and it prevails the high temperatures in the combustion chamber. Further, the inherent oxygen content in alcohol and the higher operating heat cause the complete combustion and oxidation of the soot particles which reduce smoke emissions. Smoke densities were calculated by opacity test for the fuels. As the load is increased the rich mixture is formed and increases smoke intensities. The variation of exhaust smoke intensity for brass piston material is shown in Figure 9.

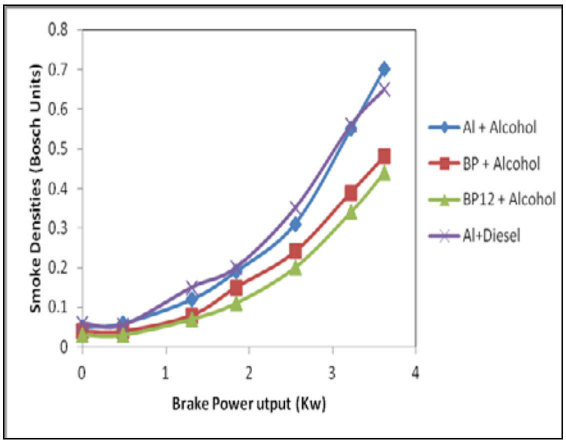



**Figure 9.** Comparison of Smoke intensity with power out put

From the graph above, it is observed that the brass piston showed the lowest smoke emissions over the entire operating range and the reduction is about 19.8 percent. This will increase further with BP12 due to the turbulence generated by the piston. The drop is about 16 percent compared to BP.

*2.3.5. Hydrocarbon Emissions*

The variations of hydrocarbon emissions with power output for the different piston materials are illustrated in Figure 10. The main sources of these emissions in the diesel engine are lean mixing, burning of lubricating oil, and wall quenching. In spite of the rich air-fuel mixture due to the lower volumetric efficiency, the HC emissions are reduced considerably due to the completion of the combustion of the fuel with hot combustion chamber. From the graph, it is observed that the maximum reduction is with BP12. This is because of its material properties and turbulence generation. The reduction is about 6.26% compared to BP at the rated load.

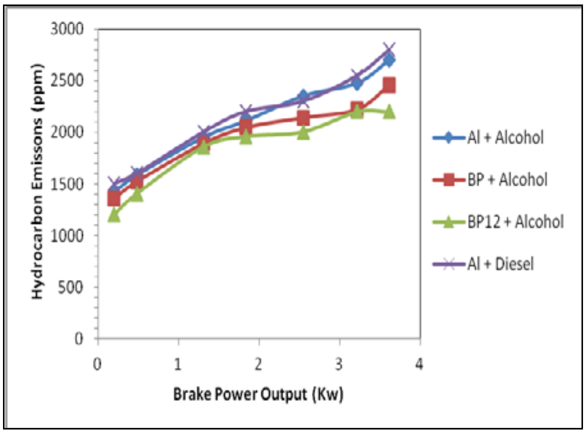



**Figure 10.** Comparison of Hydrocarbon emissions with power output

*2.3.6. Nitrogen oxide Emissions*

Figure 11 illustrates the variation of NOx emissions with various piston inserts of the ceramic insulated engine. The amount of NOx present in the combustion chamber, relies on the evaporation rate of the fuel. This increases the formation of the NOx emissions with the availability of oxygen and the higher prevailing temperatures in the chamber.

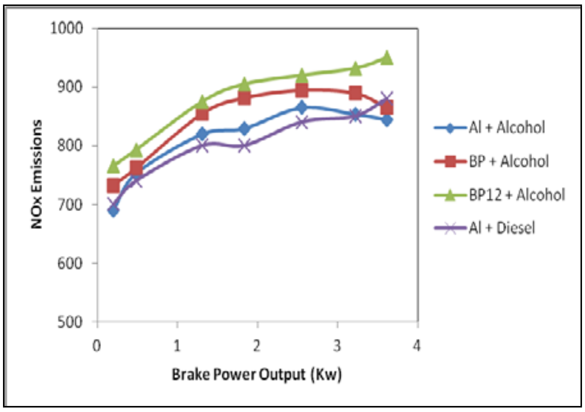



**Figure 11.** Comparison of Nitrogen Oxide emissions with power output

As the temperature with BP12 is higher, the increase in NOx emissions is also more and is about 4% compared with base aluminum piston. The emission with BP is in between aluminum piston and BP12.

## Conclusions

Following are the conclusions drawn based on the experimental results obtained while operating single cylinder ceramic insulated air gap diesel engine fuelled with diesel and alcohol:

- The brake thermal efficiency and exhaust gas temperatures with brass piston are more because it acted as a regenerator.
- With turbulence, BP12 performed well in terms of emissions and efficiency.
- The insulated components in the engine increase the available energy at the chamber and are evident with the exhaust gas energy which can be used to run a low pressure turbine.
- The volumetric efficiency of the ceramic engine is reduced with the higher operating temperatures of the chamber. This can be recovered with turbocharging system.
- With the higher temperature in the chamber NOx emissions are more with BP12 compared to all other pistons.
- With the higher operating temperatures of the ceramic engine, the performance of the lubricating oil deteriorates resulting higher friction. This problem can overcome with new liquid lubricants or solid lubricants.
- The higher temperature in the chamber enables the use of low cetane fuels and confers the multi-fuel handling capability.

Good homogeneous mixture formation, complete combustion and lower pollutant emissions are the main important factors for the high-quality diesel engine performance. These factors are highly influenced by viscosity, density amount of oxygen present in the fuel, etc. For alcohol, these factors are in a considerable range and can be modified easily. With the burning of alcohol in the diesel engine, it can be considered as a preferable replacement for the diesel fuel, thereby promoting our economy and making farmers self-sufficient.

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