FUEL AND ENERGY CONSUMPTION DECREASE IN ORDER TO PRODUCE PIG-IRON FOR STEELMAKING USING INJECTION REDUCING GAS IN THE BLAST FURNACE

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Abstract: The steel industry consumes a great amount of energy and much of it is consumed in the blast furnace. Increasing the amount of pig-iron produced in blast furnaces led to the mining metallurgical sector increasing efforts to cover ore and coke needs.

In terms of obtaining the pig iron of iron ore and metallurgical coke, through traditional flow, there are high costs of the finished product (pig-iron for steelmaking or iron foundry) due in particular to raw material and energy costs. Solid fuel used in blast furnace, coke, is not only poor but also very expensive, its unit cost equalizing the cost of the pig iron.

The fundamental objective of this paper is to establish further economic and technical analysis supporting the limits of rational use of injection reducing gas in the tank furnace in order to obtain improved furnace operating parameters values, to reduce material and energy consumption and to grow the productivity.

Keywords: pig-iron for steelmaking, reducing gas, blast furnace, specific consumption of metallurgical coke

1. INTRODUCTION

In terms of obtaining the pig iron of iron ore and metallurgical coke, through traditional flow, there are high costs of the finished product (pig-iron for steelmaking or iron foundry) due in particular to raw material and energy costs. Solid fuel used in blast furnace, coke, is not only poor but also very expensive, its unit cost equalizing the cost of the pig iron.

Current technology for obtaining pig-iron from ore and coke is competed strongly with unconventional melting reducing technologies (Corex, Kawasaki, CBF, Mildrex, etc.). The main advantage of these new technologies is completely eliminating of chemical coke sector and partially the ore agglomeration from the traditional flow.

Since the blast furnace is still the aggregate which provides over 85% of pig-iron, the researches in this area have aimed at reducing energy and material consumption. Great opportunities for reduction of all specific consumption and manufacturing costs are provided by using at blast furnace some of materials and unconventional energy resources (coke and ore pellets mixed unconventional crowded, auxiliary fuel, reducing gases, unconventional thermal sources, etc.).

Currently there are known significant achievements in the field studied, all about but belonging to companies in Germany, Japan, USA, and Russia. Remarkable results are communicated in terms of frequent use of modern techniques which have led to continuous decrease of consumption in blast furnaces.

The fundamental objective of this paper is to establish as a result of techno – economic analysis supporting the rational limits of use the injection of reducing gas in the furnace chamber to obtain improved values of operating parameters of the furnace, reducing material and energy consumption, and to grow the productivity.

2. BLOWING REDUCING GAS IN THE TANK FURNACE

The blowing gas in the furnace with high levels of carbon monoxide and hydrogen is one of the newest methods to reduce specific consumption of coke and growing blast of furnace productivity. In connection with this method are known a few of the experimental results carried out either at pilot scale, or industrial scale, partly confirming the results of theoretical calculations performed.

Thus, at the plants Japan-Hirohata is used the blowing reducing gas into the tank furnace consisting mainly of hydrogen and carbon monoxide produced by dissociation off fuel oil outside of the furnace, in a reactor, with Texaco process, this being characterized by partial oxidation of fuel oil with a mixture of oxygen and water vapor. The gas produced by this process becomes an optimum composition, with high content of hydrogen and carbon monoxide and water vapor minimum content and carbon dioxide and carbon by dissociation to 1600^0C.

Since the dissociation gases have to be blown into the tank at a temperature of 1200^0C, they require cooling to 400^0C, thereby safeguarding the possibility of using available heat for recovery boilers. This method allows obtaining a replacement ratio 1[kg coke/kg fuel]. At the plant Azovstali were performed experiments using preheated reducing gas in a furnace to 1300 m^3 by blowing them with the help of gas holes in the same vertical plane with the mouth of the wind, but at a higher level of 600 mm and under 30^0 angles to the horizontal.

These gases were obtained by means of catalytic conversion with steam of methane gas, using three transducers - preheaters, working in regenerative catalytic cycle of nickel. As shown by experimental phase of operation of the plant conversion, this method has some critical shortcomings and cannot be recommended for application to the furnace on industrial scale.

Experimental batches performed in the blast furnaces have confirmed the prospect of the blowing with preheated reducing gas and the urgent need to develop more effective methods to achieve them. In some subsequent experiments, the preheated reducing gas was introduced into the crucible of the blast furnace through a complex installation of blast holes with separate channels for gas and air, but associated with a single cooler.

The main deficiencies of this installation proved to be weight and gauges too large of the complex holes and some design flaws related to the length of the gas nozzle. Settling a reference period of the methane gas blowing, and one combined injection with methane gas and reducing gas, could be appreciate that while methane gas has been completely replaced with a reducing gas, the blast furnace productivity was increased by 9,2% and specific coke consumption decreased by 2,6%, and compared the combined use of methane gas and reducing the productivity increased by 0,4% while the specific coke consumption decreased by 3,5%. Tests of experimental furnace at L'Airba have showed that the combined injection of the etalaj gas conversion and the fuel oil through the main mouths have the additive effects.

This technique allowed reducing coke consumption of 275 [kg / t pig-iron] but attempts were allowed to answer at questions relating to increasing the production and penetration of conversion gas and into a large size furnace. At the same time as many indices can achieve an increase in the blast furnace productivity.

Economic conclusions show that an index replacement 0,25 [kg coke /m^{3}gas], the maximum which can be get in an industrial the furnace may already have advantages. It may provide in on not too distant future, getting very low coke consumption. All new decreases of coke consumption can be achieved only by replacing the fuel with others that will be less expensive and available in greater quantity. Should we always consider the relative prices of different types of energy prices that it can change unpredictably over time. It is therefore necessary to know that there are other technical possibilities and economic examination of the results that they can result in conditions of the moment.

The injection at the bottom of the tank of a hot gas conversion, containing about 90% hydrogen plus carbon monoxide, should enable the strong growth of the shown reductions. Best place for this injection will be the recovery area where the temperature does not allow carbon to react on Bell-Boudoard reaction.

If it is reached at reduction, virtually all iron oxides in solid, this Bell -Boudoard reaction is completely suppressed in inside the furnace. It thus saves a large amount of carbon reduction and thermal needs of the work area at which the endothermic reactions are strongly reduced.

The calculations allow to be made gains of coke achievable due to the injection of reducing gas in the tank. It can be said that the among various possible techniques, the combined injections of reducing etalaj gas and fuel oil in the wind mouths is a very interesting opportunity to further reduce consumption of the coke in the blast furnace. This has been clearly demonstrated. The economic calculations show that this process can be perfectly profitable in many circumstances, there remains only to prove the validity of test results for transposition of the industrial furnace.

The plan to inject the hot gas conversion, is situated at 3,6 m height etalaj's i.e. above the plane wind mouth. The injection is done through the mouths of wind, which have cooling circuits, these mouths of wind are in equal numbers with mouths and blowers are powered by an annular pipe.

The distance between the overheated furnace and pipeline allows placing an isolation valve, the valve instead of hot air. The conversion gases intrusion inside the furnace is good and it depends on the amount of gas injected.

It is a known method of obtaining reducing gases from methane converted to CO_2 and H_2O, the reducing gas with low content of CO_2 and H_2O.

It was calculated the effect that it will have on the operation of the furnace, blowing reducing gases on the basis of tank, gases produced by methane conversion with recycled blast furnace gas.

Figure 1 shows schematically the balance and the chemical composition of the gas in case the furnace operation under these conditions, at a 1000^0C temperature of insufflated furnace the gas.

Comparing the results of obtained calculations with those from normal operation of a furnace (using methane blowing through the wind mouths) results that we get a coke economy, about 100 [kg/t pig-iron], and increase the furnace productivity by 10%. The process was studied in an experimental facility consisting of a furnace equipped with loading mechanisms, two air cowpers, two converters for the catalytic regeneration with methane of recycled gas and related facilities for air insufflations, purification and gas recirculation, measuring and control devices.

In most blast at the tank furnace, the recirculated and regenerated blast furnace gas so as to the oxidation rate of gas $(CO_2 + H_2O) / (CO + H_2O + CO_2 + H_2) = 9\%$ and assuming a degree of use $(CO + H_2)$ wüstit's at 25%, calculations show:

- the replacement ratio of coke with a reducing gas (including nitrogen), instilled in the tank is about 0,084 [kg coke / Nm^3], or about 0,140 [kg coke/Nm^3] $(CO + CO_2 + H_2O + H_2)$;
- the replacement ratio of coke used in the regeneration of a natural gas furnace gas from 0,7 to 0,75 [kg coke/Nm^3CH_4], compared to about 0, 57 [kgcoke/Nm^3CH_4], that would instill only converted to methane and water vapor with the same degree of oxidation.

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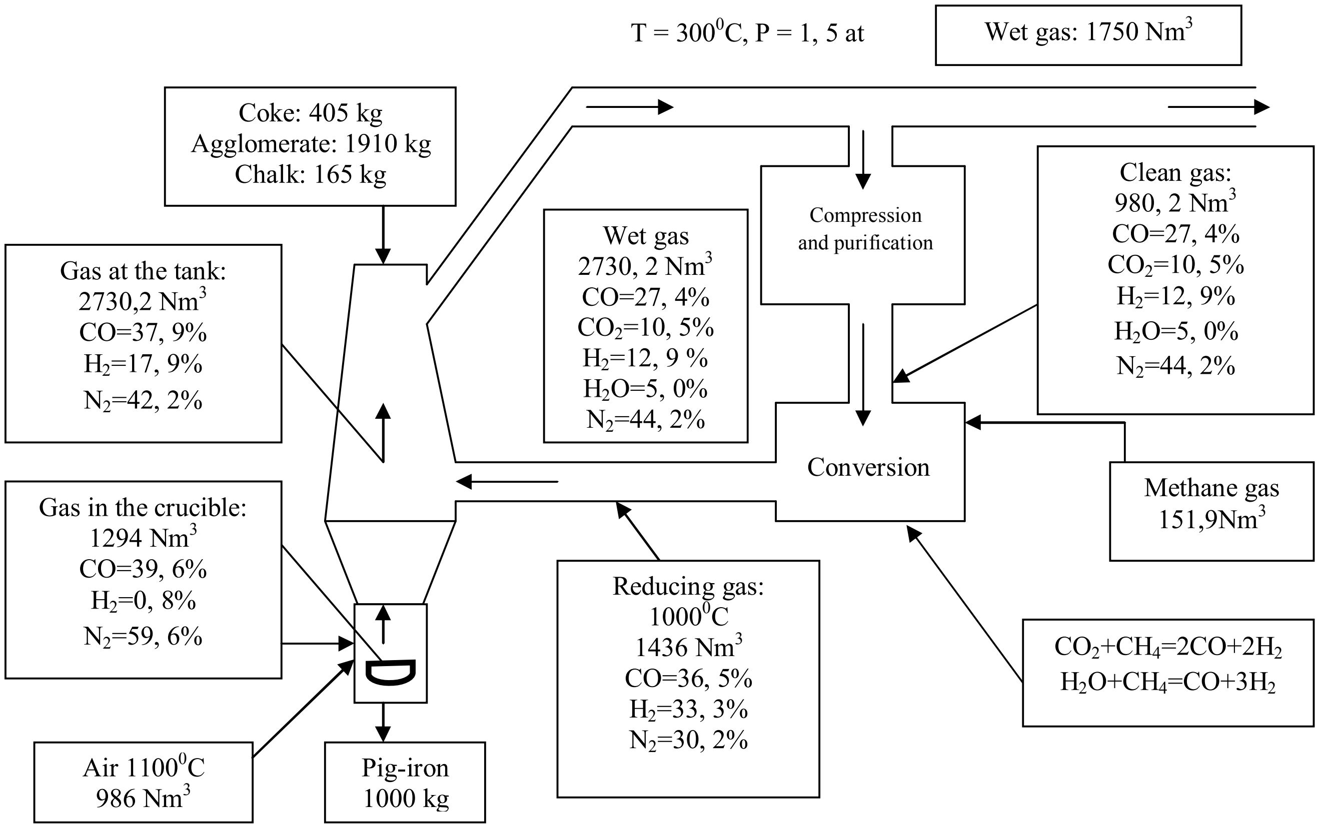

Figure.1. The blast furnace material balance when using reducing gas in the tank furnace

3. AVERAGE INDICATORS FOR REDUCING GAS BLAST FURNACE OPERATION.

A. Indicators that characterize production were calculated and are as follows:

A.1. the average daily expressed in [t pig-iron/calendar days]; P_c = 345,787 [t pig-iron / calendar days]

A.2. the average daily expressed in [t pig-iron/actual days]; P_{ef} = 348,417 [t pig-iron/actual days]

A.3. the average hourly rate expressed in [t pig-iron/ h]; P_h = 14,517 [t pig-iron/ h]

A.4. Index of use of the furnace [t pig-iron/m^3 actual days]; $I_u = P_{ef} / Vu$ = 348,417/250 = 1, 4 [t pig-iron/m^3 actual days].

B. Operating intensity:

B.1. Technical coke combustion intensity $I_a = K_t P/VuNef$ [t_{coke}/m^3 actual days],

Where P - total production of pig iron, P = 10719, 4 [t pig-iron/31 days]

Nef - number of days actually working, Nef = 30,766

I_a = 575, 2 * 10719, 4 / (250 * 30,766) = 801,638 [kg/m^3 actual days] = 0, 8017 [t/ m^3 actual days]

B.2. Equivalent intensity of coke combustion $I_{k,\ CH4}$ = 1

$K_e = K_t + I_{k,\ CH4} * Q_{CH4}$ = 575, 2 + 80, 3 = 655, 5 [kg coke ec.]

$I_a = K_e * P / (Vu * Nef)$ [t coke ec. /m^3 actual days]

I_a = 655, 5 * 10719, 4 / (250 * 30,766) = 913, 55 [kg coke ec. /m^3 actual days]

I_a = 0.91355 [t coke ec. /m^3 actual days]

C. Charging:

Charging remains largely the same as the functioning without reducing gas. It will change the specific fuel consumption and charging unit.

C.1. Net charge (M), M = 2089,615 [kg]

C.2. the removal of iron (s), s = 1/M * 100 = 1 / 2, 089 615 * 100 = 47.86%

C.3. Setting the boot drive

- Charging scheme used: KM
- Net volume of skip: Vu = 4, 5 [m^3]

It is considered that is used an skips for coke with γ_k = 500 [kg/m^3] (for technological coke)

- Weight skip with technological coke, G_{kthl} = 405 * 500 = 2250 [kg / UI]
- Technological coke consumed per ton pig-iron:

1) $K_{thl} = 100K_t/100-w$

2) K_{thl} = 575, 2*100/ (100 - 6.059) = 612, 3 [Kg /t pig-iron]

- The amount of iron obtained from a charging unit: G_{kthl} / K_{thl} = 2250/612, 3 = 3,68 [t pig-iron / UI]
- The amount of pig-iron and ore loading unit. For calculating used the specific consumption:
- Krivoi Rog Ore $G_{MK\text{-}R}$ = 459, 83 * 3, 68 = 1692, 18 [kg / UI]
- Indian ore gross G_{MIb} = 529, 134 * 3.68 = 1947, 22 [kg / UI]
- Indian ore screening G_{MIc} = 23, 8 * 3, 68 = 87, 584 [kg / UI]
- Krivoi Rog pellets Gp = 322, 695 * 3, 68 = 1187, 52 [kg / UI]
- Iacobeni ore G_{MI} = 19, 665 * 3, 68 = 72, 37 [kg / UI]

-Indian ore sorting G_{MIs} = 260, 22 * 3, 68 = 957, 61 [kg / UI]

- Iron ore G_{MT} = 30, 04 * 3, 68 = 110, 55 [kg / UI]
- Agglomerate G_{AH} = 98, 466 * 3, 68 = 362, 36 [kg / UI]
- Pig-iron waste G_D = 16, 92 * 3, 68 = 62, 27 [kg / UI]
- Fluff G_S = 19, 425 * 3, 68 = 71, 49 [kg / UI]
- Chalk Gc = 309, 42 * 3, 68 = 1138, 67 [kg / UI]
- Technological coke G_{kthl} = 612, 3 * 3, 68 = 2250 [kg / UI]
- Total charging (ore + coke + chalk) Mtot = 9939, 824 [kg / UI]

Volume occupied by the material of the load:

- Krivoi Rog ore $V_{Mk-R} = G_{MK-R} / \gamma_{Mk-R}$ = 1, 69218 / 2, 0 = 0, 847 [m^3]
- Indian ore gross $V_{MIb} = G_{Mib} / \gamma_{Mib}$ = 1, 94722 / 2, 5 = 0, 779 [m^3]
- Indian ore screening $V_{Mic} = G_{Mic} / \gamma_{Mic}$ = 0, 087584 / 2, 5 = 0, 036 [m^3]
- Krivoi Rog pellets $V_{PK-R} = G_{Pk-R}/\gamma_{Pk-R}$ = 1, 18752 / 2, 5 = 0, 476 [m^3]
- Iacobeni ore $V_{MI} = G_{MI} / \gamma_{MI}$ = 0, 07237/ 1, 85 = 0, 04 [m^3]
- Indian ore sorting $V_{Mis} = G_{MIs} / \gamma_{MIs}$ = 0, 95761 / 2, 5 = 0, 384 [m^3]
- Iron ore $V_{MT} = G_{MT} / \gamma_{MT}$ = 0, 11055 / 1, 85 = 0, 06 [m^3]
- Agglomerate $V_{AH} = G_{AH} / \gamma_{AH}$ = 0, 36236 / 1, 85 = 0, 196 [m^3]
- Pig-iron waste $V_D = G_D / \gamma_D$ = 0, 06227 / 4 = 0, 016 [m^3]
- Fluff $V_S = G_S / \gamma_S$ = 0, 07149 / 5 = 0, 015 [m^3]
- Chalk $V_C = G_C / \gamma_C$ = 1, 13867 / 1, 6 = 0, 712 [m^3]
- Technological coke Vkthl = G_{kthl} / γ_{kthl} = 2, 250 / 0, 5 = 4, 5 [m^3]

Total volume = 8, 061 [m^3]

It follows that the charging scheme remains the same: KM

C.4. Specific consumptions of technical coke.

- Specific consumption of technical coke K_t = 575, 2 [kg / t pig-iron]
- Specific consumption of technology coke Kthl = $100K_t$ / (100-w) = 612 [kg / t pig-iron]
- Specific consumption of supply coke

K_S = Kthl + powder; K_S = 643, 09 [kg / t pig-iron]

- Specific consumption of natural gas Q_{CH4} = 80, 3 [Nm^3/t pig-iron]
- Specific consumption of reducing gas $Q_{G.R.}$ = 558, 055 [Nm^3/t pig-iron]

C.5. Percentage of agglomerate and pellets:

- Total consumption of ferrous raw materials: 1780, 195 [kg / t pig-iron]…100%
- Specific consumption of agglomerate: 98, 466 [kg / t pig-iron] ... 5, 53%
- Specific consumption of pellets: 322, 695 [kg / t pig-iron] ... 18, 127%
- Specific consumption of ore…76, 343%

D. Operating Parameters

- Blast furnace gas flow [Nm^3/t pig-iron] Q_{gas} = 3059, 04 [Nm^3/t pig-iron]
- Air flow calculated [Nm^3/t pig-iron]:
- Air humidity: Q_{ah} = 1802, 27 [Nm^3/t pig-iron]
- Dry air: Q_{da} = 1784, 27 [Nm^3/t pig-iron]
- Calculate air flow [Nm^3/h] Q_{af} =1802, 27 [Nm^3/t pig-iron] *14, 517 [t pig-iron /h] = 26164 [Nm3 / h]
- Air flow [Nm^3/m^3 useful volume and minutes] Q_a= 26164 / 69,250 = 377, 81
- Hot air temperature: ta = 1064,5^0 C
- Insufflations temperature for the reducing gas: t_{GR} = 1000^{0}C
- Blowing air pressure: Pa = 689,7 [mmHg]
- Gas flow [Nm^3/h] Q_{CH4} = 80, 3 [Nm^3/t pig-iron] * 14, 517 [t pig-iron / h] = 1166 [Nm^3 / h]
- Characteristics of slag and pig-iron remain unchanged.
- Characteristics of blast furnace gas:
- The quantity of blast furnace gas [Nm^3/h] Q_{bf} = 3059.04 [Nm^3/t pig-iron] * 14, 517 [t pig-iron/ h] = 44408 [Nm^3 / h]
- Blast furnace gas temperature: tg = 350^{0}C
- Blast furnace gas composition (% volume) CO = 25, 128%, CO_2 = 14, 193%, CH_4 = 0, 587%, H_2 =7, 561%, N_2 = 52, 531%

E. Balance data

E.1. Passing manganese in pig-iron (%) [Mn] / $\langle Mn\rangle_{all}$ = (7, 2 / 10, 424) * 100 = 65, 08%

E.2. Index distribution of sulfur

$L_{S\ (nec)}$ = 29, 8

L_S = (S) / [S] = 1, 135 / 0, 03 = 37, 8

E.3. Yield carbon monoxide η_{CO}= $CO_{2R.i.}$ * 100 / ($CO_{2R.i.}$ + CO_f)

Where: CO_f = COg.f. - COm.v. [Nm^3] = 768, 65-2, 4 = 766, 25 [Nm^3]

η_{CO} = 360.58*100/ (360.58+766.25) ≈32%

E.4. Hydrogen yield

ηH2 = $H_{2R.i.}$*100/$H_{2\ all}$ =7, 337*100/29, 35 = 25%

E.5. Total heat consumption

Q_h= 3272, 335 * 10^3 [Kcal / t pig-iron]

E.6. The difference in balance: 248, 523 * 10^3 [Kcal / t pig-iron] = 7, 586 [%]

E.7. Thermal yield of the blast furnace

η_t = Qu * 100 / Qintr, [%]

Qu = 2554, 066 * 10^3 [Kcal / t pi-iron]

η_t = 2554, 066 * 10^3 * 100 /3272, 335 *10^3 = 78%

E.8. Carbon yield of the blast furnace

For this case (insufflations reducing gases) is not calculated.

4. ECONOMIC CONCLUSIONS

The reducing gases were obtained from the process of catalytic conversion of methane gas with carbon dioxide and water vapor from the recirculated furnace gas. For economic calculation was considered that the daily average production and the volume index remain unchanged although it may provide an increase in production due to lower average daily volume of gases from the crucible.

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Following the theoretical calculation of the furnace number 1 – IV Călan has reached the following conclusions:

The burning intensity decreases for both technical and coke equivalent due to reduction of coke consumption by the reducing gas blowing in the tank. It was obtained a reduction of coke per ton of iron rather high 81,72 [kg / t pig-iron] leading to a decrease in the cost per ton of pig-iron.

With the decrease of coke consumption, the flow of air blown has decreased too and thus the amount of gases from the crucible.

The gas flow of blast furnace increased significantly due the reducing gases insufflations and also increased the percentage of carbon dioxide gas, which shows a better use in the furnace.

It was decreased very much percentage of hydrogen and methane which makes the blast furnace gas obtained to be with relatively high calorific value 1010 [kcal/Nm^3].

Besides reducing the consumption of coke, it is obtained a combustible gas that can be used for different purposes. With the decrease of coke consumption per ton of iron decreases and the consumption of gas, so that the ratio $Qcoke/Q_{CH4}$ to remain constantly.

The gas temperature at the neck of blast furnace will have a slight increase, reaching 350-400^{0}C due to the introduction besides the reducing gases a significant amount of heat (t_{GR} = 1000^{0}C) into the tank.

The heat of reducing gas has led to an overall increase in total quantity of heat in and thus the gap of balance of 6,489% to 7,586%.

The yield carbon monoxide and hydrogen yield were increased significantly, which shows a better use of gases in blast furnace operation in opposite with cases when the furnace operating without reducing gases insufflations.

But the furnace thermal efficiency decreases from 82,781% to 78,05% due to the large amount of furnace gas and the high temperature that it has, and due to the temperature difference of balances higher at the reducing gas furnace operation.

Despite these small drawbacks, the use of blast furnace gas becomes profitable and with the price conditions existing, the economy per ton of iron is 34,819 RON / t pig-iron. The methane is only what is consumed for the reducing gas production.

The process of instilling the reducing gases in tank, obtained by converting of methane with blast furnace gas, recirculated blast furnace gas, allowing better use of blast furnace gas. In percent, 58,717% of the total gas furnace is used and only the remainders are sent to other customers.

As a general conclusion, appears that blast furnace operation with reducing gases blast at the base of the tank is a process for future and with success to replace a significant amount of coke, fuel that is becoming increasingly expensive, with minimum expenses.

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