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05019

Distribution
LIMITED

ID/WG.164/ 27
8 October 1973

Original: ENGLISH

United Nations Industrial Development Organization

Expert Group Meeting on the Manufacture of
Proteins from Hydrocarbons

Vienna, Austria, 8 - 12 October 1973

PRODUCTION OF SCP FROM HYDROCARBONS ECONOMICS 1/

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id.73-6827

Although it has been known for decades that certain micro-organisms can oxidise hydrocarbons, it is only in the fifties that it was appreciated that some can utilise hydrocarbons as growth substrate. Its full implication in terms of production of SCP as a source of feed or food was only measured following publication of the work done by BP at the instigation of A. Champagnat and with the advice of Professor Senez.

Progress on the BP work has been reported at other conferences and in papers, by Champagnat, Laine and Shacklady. It is fair to say that the result of work in various academic or industrial laboratories has supported also a great number of publications. However, not much has yet been published on the economics of SCP production, probably because very few of the groups involved have worked at a large enough scale to obtain meaningful data in terms of operating or capital costs.

Let us consider firstly possible feedstocks.

n-Paraffins have been considered first, either diluted with other hydrocarbons in the middle distillate fractions of crude oil, or pure after extraction from middle distillate by molecular sieves and additional chemical treatment to obtain medicinal grade alkanes.

Methane was suggested as a cheaper source of hydrocarbons, avoiding specially all problems of removal of residual hydrocarbons. But, so far, not much successful work has been reported for reasons which will become apparent later and attention has moved from methane to methanol at the instigation of ICI for reasons that Dr. D. G. MacLennan and J. Gow have recently pointed out,

"Methanol is a particularly suitable SCP raw material for several reasons:

(i) It is completely miscible with water.

(ii) It can be produced from a very wide range of hydrocarbon feedstocks ranging from coal to naphtha and natural gas.

(iii) It can be produced in virtually unlimited quantities in any area of the world having any form of fossil fuel supplies and is not limited by the output of a refinery in the same way as are normal alkanes.

(iv) Its method of production, which involves catalytic degradation of the hydrocarbon feedstock to CO and H_2, precludes the presence of potentially carcinogenic polycyclic hydrocarbons.

(v) The growth of micro-organisms on methanol requires less oxygen than does growth on normal alkanes - an important factor in the overall process economics.

(vi) Finally, if a methanol plant is built as an integral part of an SCP plant, considerable quantities of heat liberated by the methanol synthesis can be used to provide the sterilisation heat required for the fermentation process."

The following table will give an indication of the costs involved, where we have included data on molasses, which are already widely used as yeast substrate.

	Feedstock Cost ¢/lb.	Yield lb. SCP/ lb. Substrate	Substrate cost ¢/lb. of SCP
Molasses (50% assimilable carbohydrates)	1-2	0.25	4-8
n-Paraffins	3-4	1	3-4
Gas Oil	1	1	1
Methanol	2	0.45	4.5
Methane	0.25-1	0.6	0.4-1.7

The low figure for molasses corresponds to a cost in producing countries whereas the high one corresponds to a cost in importing countries, especially in Western Europe.

The bracket of figures for methane reflects the possible difference of value at the crude oil well head in a producing country of the Middle East and in Western Europe where it is costed at fuel oil value.

But an economic assessment of SCP production must also take into account the oxygen requirement and heat evolved during fermentation. The following stoichiometric equations can be written approximately.

Carbohydrate/Yeast

$1.8\ CH_2O + 0.8\ O_2 + 0.19\ NH_3$ + other essential elements (P, K, S etc.).

$\rightarrow (CH_{1.7}O_{0.5}N_{0.19}Ash)$ (Cells) $+ 0.8\ CO_2 + 1.3\ H_2O + 80{,}000$ kcals.

n Alkane/Yeast

$2\ CH_2 + 2\ O_2 + 0.19\ NH_3$ + other essential elements (P, K, S etc.)

$\rightarrow (CH_{1.7}\ O_{0.5} N_{0.19} Ash)$ (Cells) $+ CO_2 + 1.5\ H_2O$ + 200,000 kcals.

Methanol/Bacteria

$1.72\ CH_3\ OH + 0.23\ NH_3 + 1.51\ O_2$ + other essential elements

$\rightarrow 1.0\ (CH_{1.68} O_{0.36} N_{0.23} Ash)$ (Cells) $+ 0.72\ CO_2 + 2.94\ H_2O$ + 185,000 kcals.

Methane Bacteria

$2.6\ CH_4 + 0.23\ NH_3 + 4.15\ O2$ + other essential elements

$\rightarrow 1.0 (CH_{1.68} O_{0.36} N_{0.23} Ash)$ (Cells) $+ 1.6\ CO_2 + 4.7\ H_2O$

It can be noted that fermentation on methanol, paraffins and methane requires respectively 2, 2.5 and 5 times more oxygen per unit of cell than on molasses, the heat evolutions being also roughly in the same ratios.

Assuming that the power required for oxygen transfer to the cells is in the same ratio, the following table can be derived. For this purpose we have used the minimum and maximum figures published in terms of Kwh per pound of yeast produced from molasses and assumed a cost of 1¢/Kwh.

	Ratio of O_2 Requirement	Energy Consumption ¢/lb.
Molasses	1	0.25 - 0.5
n-Paraffins	2.5	0.6 - 1.25
Gas oil	2.5	" "
Methanol	2	0.5 - 1
Methane	5	1.25 - 2.5

In order to make a comparative estimate of the impact of heat evolution we have assumed that cooling water at 18/20°C is available (typical N.W Europe sea-board location), that fermentation with yeast takes place at 30°C, whilst, for methanol and methane, bacteria are used and grow at 40°C, hence increasing the heat transfer efficiency by a factor of 2.

	Fermentation Temperature	Heat Evolution Ratio	Relative ratio of coolant Circulation	Cost ¢/lb.
Molasses	30°C	1	1	0.25
n-Paraffins	30	2.5	2.5	0.6
Gas oil	30	2.5	2.5	0.6
Methanol	40	2	1	0.25
Methane	40	5	2.5	0.6

If we sum up the costs given in the 3 tables after due account of the fact that if gas oil is used, the costs must be multiplied by 1.2 to take into account the loss of lipidic material suffered during the final stage of purification by solvent extraction, we obtain the following extreme costs:

	¢/lb.	
Molasses	4.50	8.75
n-Paraffins	4.2	5.85
Gas oil	2.65	3.45
Methanol	5.25	5.75
Methane	2.25	4.8

A direct comparison of the figures would be misleading. Yeast grown on molasses is normally separated from spent medium by centrifuges and, as published already, the same order of efficiency can be expected from industrial centrifuges for yeast grown on paraffins. On the other hand, because of the much smaller size of bacteria, the efficiency of centrifuges for the harvesting of a biomass obtained on methanol or methane is probably reduced by a factor of 8 or 10.

ICI have said that to overcome this problem they have introduced, "a prior concentration stage such as floculation or flotation. However, this additional stage can be achieved relatively easily." At what cost is difficult to say.

Another point to mention, relative to the methane process, is that the exhaust gas from fermentation still contains a large portion of non-consumed methane, which, if not recycled in the system in one way or another, would add considerably to the cost.

Short of accurate data on these points, it would be pointless to continue a comparative production cost analysis and we shall concentrate now on the two processes developed by BP (Appendix 1.2). In the gas oil process the feedstock is fed continuously with an aqueous mineral medium and the yeast consumes the paraffinic fraction, which represents roughly 20-30% of the gas oil, according to the origin of the crude oil.

In the n-paraffin process, pure n-paraffins previously extracted from middle distillate are totally consumed by the yeast. In the first case the yeast biomass must be purified from residues of middle distillate by solvent extraction, the cost of which balances roughly the higher cost of the pure n-paraffins used in the second case.

If we take a typical N.W. Europe location, the breakdown of costs is as follows for a 100,000 t/a plant.

	n-Paraffins Process	Gas Oil Process
Feedstock	30-40%	10-15%
Chemicals	15-20%	20-25%
Utilities	15-20%	25%
Personnel, maintenance, Overheads, depreciation	30-35%	40%

In the gas oil process the feedstock cost will depend to an extent on the premium which can be secured for dewaxing.

In the n-paraffin process there is an additional factor to consider, which is the size of the pure n-paraffin production unit as typified in the following table.

	50,000 T	100,000 T	200,000 T
n-Paraffin cost	6-5¢/lb.	5-4¢/lb.	4-3¢/lb.

It must be appreciated that such figures are only indicative because the crude cost varies according to the origin of the crude, its content of n-paraffins, etc.

If we consider capital costs for SCP plants, it is not yet possible to draw a complete picture because so far only small plants have been built, with an experimental purpose in mind so that their cost is not really indicative. The construction of a large plant is in progress in Sardinia, but the breakdown of its cost section by section will not be available before some time. It must, however, be realised that the cost depends on the system selected for the driving of the big machines, i.e. electrical motors, steam turbines, etc.; the cost depends on the requirements, in terms of product formulation, storage facilities, product handling facilities; the total cost can also include such items as training of labour, commissioning expenses, working capital which are environmentally related.

It is, nevertheless, possible to outline a 100,000 t/a plant cost in million dollars as per the next table.

	n-Paraffin process	Gas oil process
Plant proper	25-30	30-40
Built up cost	30-40	40-50

What is the range of size of plants which can be considered?

For n-paraffins production, there is no specific limit, provided enough n-paraffins are available. In order to benefit from the low costs of large scale production, a central unit, say, 100,000-500,000 t/a could be grafted to a very large refinery and used to feed a number of smaller protein plants located according to the market requirements for SCP.

With the gas oil process, the plant must be connected with a refinery which will supply the feedstock and receive the returned non-paraffinic fraction. Consequently, the size of the plant depends on the availability of the middle distillate from the chosen refinery; it also depends on the quantity of paraffins present in the available feedstock, on the commercial value put for the raw and dewaxed middle distillate if maximum use of the premium for dewaxing is looked for.

However, the position can be summarised in rough terms, as follows in terms of protein yield

Middle distillate Boiling range	Refinery size 2M T/Y	Refinery size 10M T/Y
330-380°C		50,000
300-380°C	20,000	100,000
250-380°C (maximum potential)	50,000	200,000

It then becomes obvious that not only can SCP be produced alongside refineries of a standard size in Western Europe, but also near smaller refineries such as are now built in many parts of the world.

It is known that as plant size increases, the capital costs do not increase in proportion to scale. In his recent presentation at the MIT conference on SCP (May, 1973), Professor Humphrey suggested that the increase should be in proportion to the plant scale raised to the 0.6 power. This is probably low at this point in time. A power of 0.7/0.75 would be more appropriate, but there is no reason to believe that with the experience gained from the engineering of a number of plants his assumption will not become correct.

We have already established that our SCP, sold under the trade name TOPRINA, can find its place in Western Europe amongst other sources of protein, taking into account its high protein content and its very high nutritional value. There is no doubt in our mind that because of the progress we are making and of our experience in operating industrial plants, much smaller plants than those we are considering for Western Europe will be a viable economic proposal. I am convinced that with enough effort put into other approaches to SCP, such production will also be an economic proposal.

How will the optimal design capacity be determined?

In February, 1972 PAG issued a document on SCP pointing out that,

"The optimal design capacity of plants producing SCP from different kinds of raw material is determined by specific economic conditions related to

demand,

marketing possibilities,

raw material supply, and

fuel, power and labour resources."

At MIT Professor Humphrey made the following points clear.

"In general, economic considerations to determine the optimal scale of SCP production in various locales should take into account

1) requirements to produce a safe product,
2) demands of the country or of its separate regions for protein of this type,
3) raw materials and fuel resources available in the region of proposed plant construction,
4) expenditures on the delivery of raw materials, chemicals and other process items,
5) expenditures on the delivery of finished products to the places of their consumption,
6) existence of water, energy and labour resources in the region of plant construction,
7) extent and character of required capital investments,
8) financing facilities."

He concluded his presentation by saying,

"On the basis of fish and oil seed meal prices during the last half of '72 and the first part '73, there is every reason to be most optimistic about the future economic feasibility of SCP."

We in BP would endorse this view, basing our judgment on a broader analysis of the trend in prices of fish and oil seed meals over the years. It is our satisfaction to see that BP has pioneered an attractive new industrial, biological operation which may contribute to solving a problem which has recently become much more obvious to the general public, the protein shortage.

But let us finish on a note of warning. There is quite a difference between the engineering of a pilot plant and that of an industrial scale reliable unit; quite a difference between pilot plant and full scale industrial operation.

It is also essential to ensure the production of a toxicity-free, nutritionally good SCP and no short cut in the testing to ensure this can be risked; and no short cut in the standard of production and quality can be afforded, failing which the impact on SCP might be dramatic.

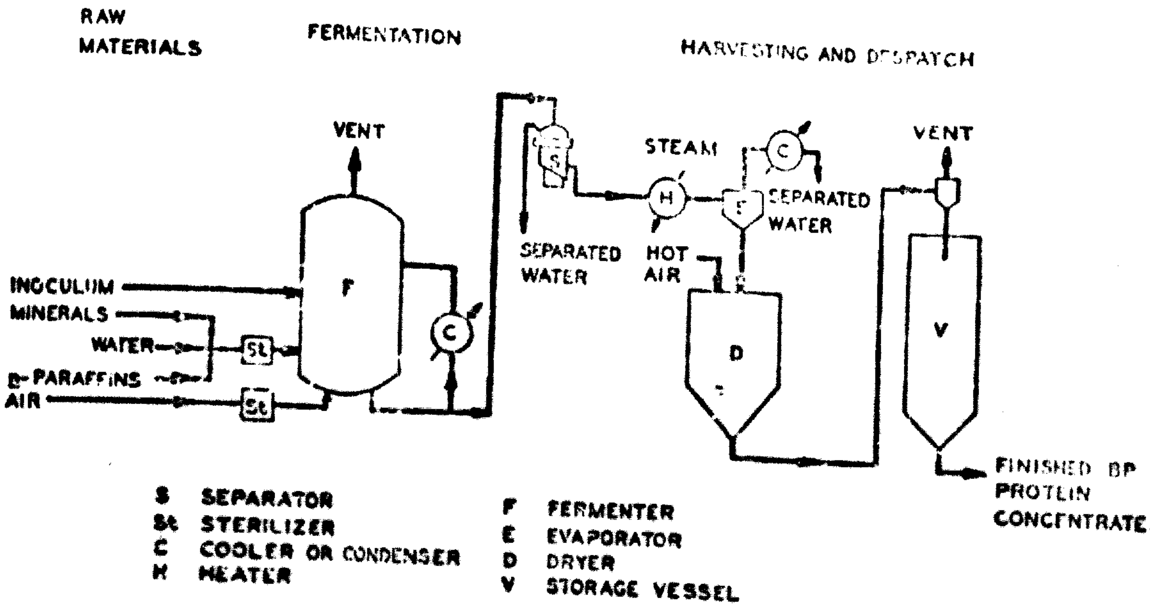

Fig. 1—This BP protein concentrate process uses n-paraffins for feedstock

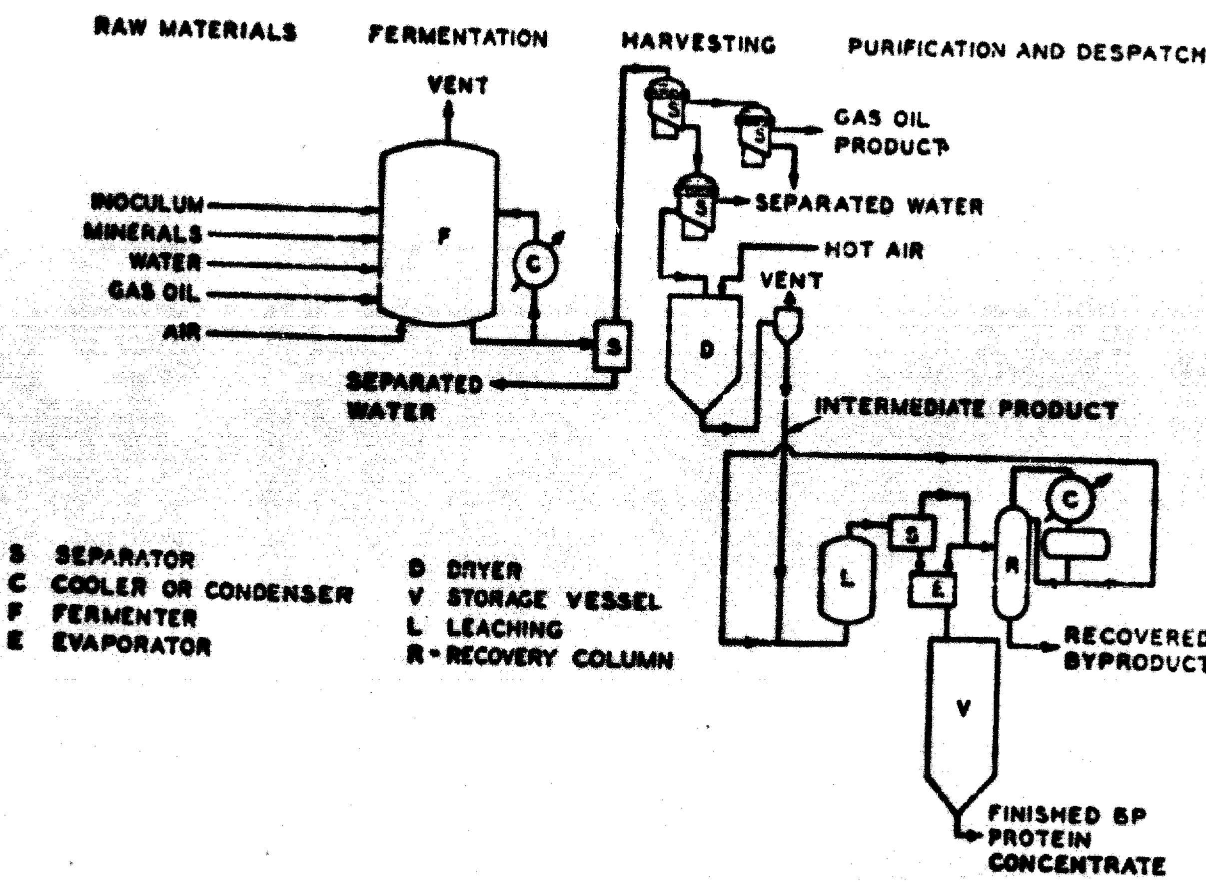

Fig. 2—This protein concentrate process uses gas oil for feedstock

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