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EVALUATION OF DUPONT ARC PROCESS FOR ACETYLENE AND VINYL CHLORIDE MONOMER PRODUCTION

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ABSTRACT

Information on the DuPont arc process for the production of acetylene from hydrocarbons is presented. Acetylene manufacturing costs have been determined for three plant sizes as a function of power cost and cost of money. A comparison of the competitive positions of arc process acetylene and ethylene as raw materials for vinyl chloride production is also presented. Scaled-up arc process plants appear to be competitive (for 2.8¢/lb ethylene and power costs below 5 mills/kwhr) if the assumed 0.71 scaling factor for the arc process is realistic.

CONTENTS

1.0 INTRODUCTION

W. E. Lobo has investigated the use of an electric arc process for the production of acetylene from naphtha feedstocks in an agro-industrial complex.[1] His choice for the process, the Orbach MHD hydrogen plasma process, was based upon low specific energy consumption and the availability of cost data at the time of the study (1967). However, to my knowledge no industrial scale acetylene plants have been built using this process.

In 1961, DuPont announced that it had developed an arc process and was constructing a plant in Montague, Michigan, to supply acetylene to their neoprene plant from hydrocarbon sources. The plant was completed late in 1963 and was operated until May 1968 when it was shut down because of "sharp reductions in the price of calcium carbide over the past few years."[2] Information on the operation of the plant obtained from DuPont and other sources is included in Section 3.0. The neoprene plant is currently using acetylene generated from calcium carbide. DuPont now has the plant up for sale and is also attempting to sell the process on a royalty basis.

This report summarizes the details of the DuPont arc process that have been disclosed and information on the process economics obtained from the DuPont Company. Finally, in order to establish the competitive position of the arc process for producing acetylene, which is a substitute for other intermediates, the production costs for vinyl chloride monomer via the oxychlorination process employing ethylene and chlorine feed are compared with vinyl chloride monomer costs using arc process acetylene and hydrochloric acid feed.

2.0 ACETYLENE PRODUCTION IN DEVELOPING COUNTRIES

Acetylene is a very versatile chemical intermediate; it is a basic raw material in the manufacture of vinyl chloride, neoprene, acrylonitrile and vinyl acetate. However, in recent years substitute raw materials have been developed for all of the processes mentioned above and the current trend is away from acetylene as a raw material. Ethylene is currently the favored raw material for vinyl chloride manufacture because of its low cost and plentiful supply (see Section 4). Ethylene can also be used in the manufacture of vinyl acetate.[3] Butadiene is now substituted for acetylene in neoprene manufacture at a new plant in Houston, Texas, and propylene is currently favored as a starting material for acrylonitrile manufacture.[3]

One prime reason for the trend away from acetylene as a raw material is its cost. Until recently most acetylene was produced from calcium carbide which is a very power-intensive process. However, costs for carbide acetylene have been quite high and are increasing according to Caudle[4] (see Figure 1). On the other hand, the cost of acetylene made from hydrocarbons has been decreasing and processes such as the BASF (partial oxidation-one stage flame), Wulff (regenerative cracking), Huels and DuPont (electric arc) have become increasingly popular. Figure 1 indicates that the costs for petrochemical acetylene are decreasing but are still well above its main competitor, ethylene. Another reason for the decline of acetylene popularity is the difficulty in manufacturing it in very large plants and transporting more than 8-10 miles by pipeline because of compression and safety problems.[3]

Acetylene does have some definite advantages for developing countries where the petrochemical industries tend to be small and the production of by-products is a major problem. The production of arc process acetylene and subsequent vinyl chloride, acrylonitrile and neoprene manufacture from acetylene produces no by-products except for hydrogen which is readily burned or used for ammonia synthesis. In comparison, an ethylene cracker produces large quantities of pyrolysis gasoline, butanes, butadiene, propylene, methane and hydrogen. Therefore the price of ethylene is very dependent upon the value of the by-products. In a developed economy, marketing of these by-products to various industries may not be a problem, but in developing countries they may have to be credited at fuel value. Ethylene crackers cannot use natural gas as a feedstock whereas many of the acetylene processes can (including the arc process). Also, mixtures up to 50-50 mole percent of ethylene and acetylene can be produced in the arc process so that polyethylene could also be produced in such a facility. Thus the arc process is much more flexible in feedstock choice, product and by-product selectivity than a conventional ethylene plant.

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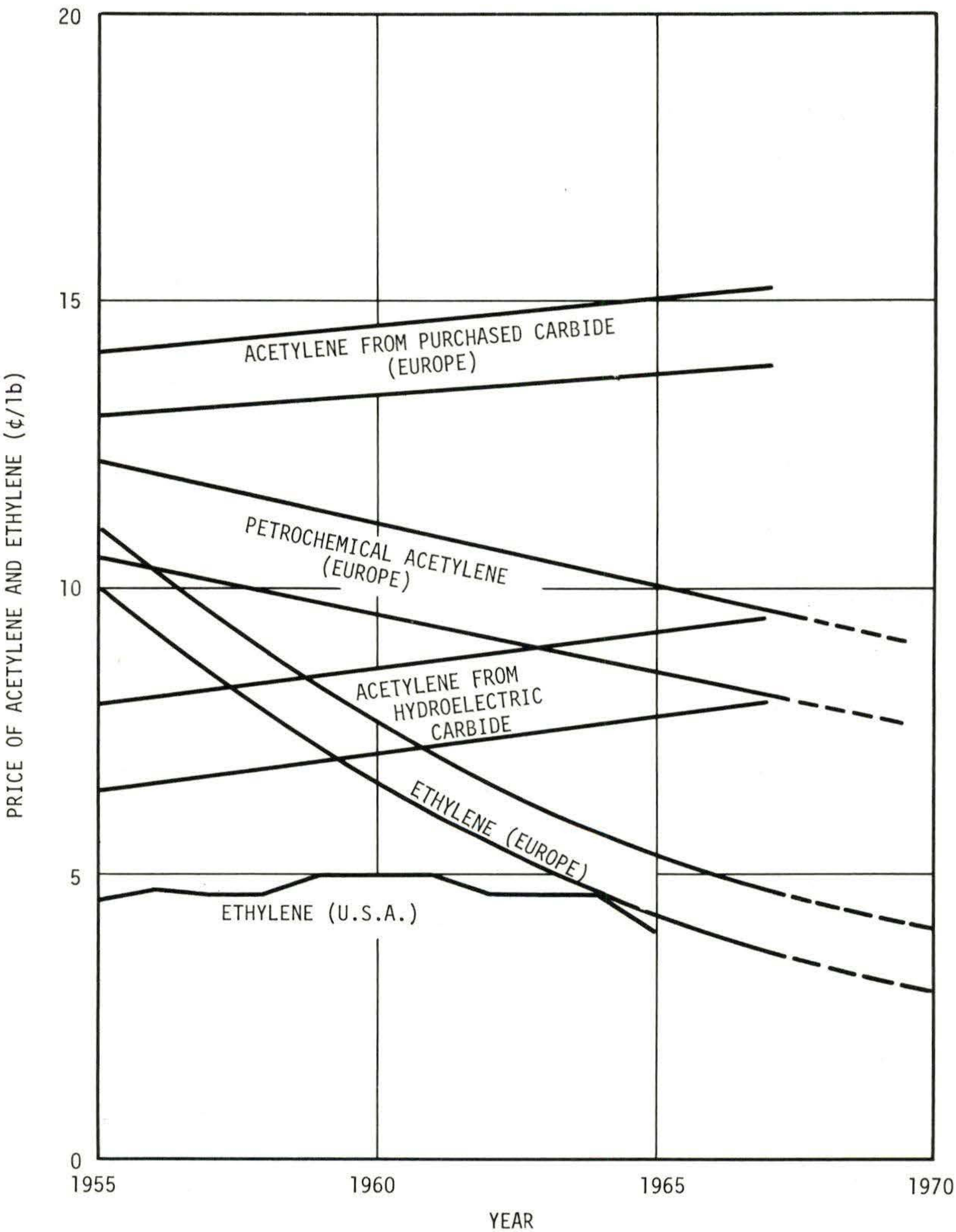


Figure 1. Price Trends of Acetylene and Ethylene.

The United Arab Republic may be taken as an example of a potential site for a small arc process acetylene-vinyl chloride facility. The UAR second five year plan (1965-70) proposed a naphtha base petrochemical facility which included a polyvinyl chloride plant of 20,000 tons/yr capacity (40 x 10^6 lb/yr).[5] The 1967 total imports of all plastics in the UAR was only about 30 x 10^6 lb/yr and assuming that PVC represents about 22% of the total (average value for developing nations) the current PVC consumption would be about 6.6 x 10^6 lb/yr. The predicted consumption in 1980 based on a 5%/yr growth rate in per capita income, a 2.5%/yr population growth rate and an income elasticity of 1.7 is 24 x 10^6 lb/yr. Therefore only a small plant would be required to satisfy local consumption even in 1980. Some export of the production from the scheduled 40 million lb/yr plant was probably planned. The growth rate of PVC production in Western Europe is high (see Figure 2)[4] so exporting probably would not be difficult if production costs were low. However, at the time of this report, construction had not been started because of the military situation.

3.0 ARC PROCESS

3.1 Process Description

The following process details were forwarded recently by Mr. R. A. Schulze of the DuPont Company.[6]

"In 1963, the DuPont Company installed production facilities for the manufacture of fifty million pounds per year of acetylene, using a proprietary arc process, wherein hydrocarbons diluted with hydrogen are pyrolyzed in an essentially continuous plasma produced by magnetic rotation of the arc. The unusual technology involved in this process required plant-scale development before acceptable on-stream time was accomplished.

"The process has been effectively demonstrated at the desired production rates with on-stream times above 90% and with a refined acetylene quality which has proved to be acceptable for use in the manufacture of neoprene. The plant performance described below, includes yields, electrical power consumption, reactor gas analysis, and refined acetylene quality which was achieved at the 50,000,000 lbs/yr scale in the commercial facilities at Montague, Michigan.

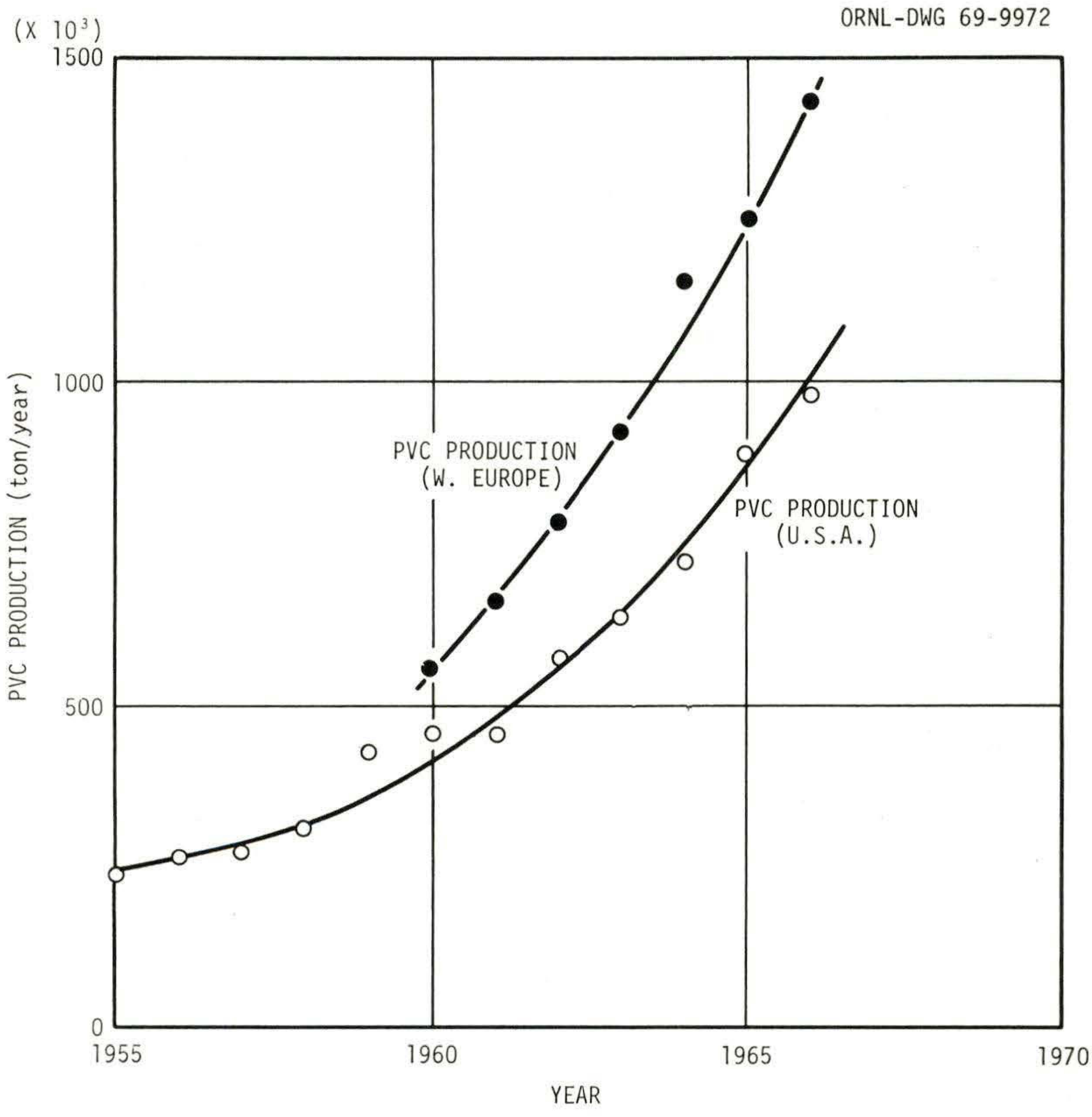


Figure 2. Growth in Production on PVC.

"The overall flow diagram of the acetylene process (Figure 3) shows the following major steps:

1. Vaporization of liquid hydrocarbon.
2. Dilution with a recycle crude hydrogen stream.
3. Pyrolysis in a direct-current magnetically rotated arc.
4. Carbon scrubbing.
5. Gas compression.
6. Acetylene recovery and refining.
7. Disposal of waste products in a steam generator.

"The arc electrical characteristics are 3100 amperes at 3500 volts direct current. The electrical current is rectified using mercury arc units which are provided with special firing circuits to accommodate rapid changes in the voltage demand of the arc. The ultra-high speed voltage demand fluctuations are damped using inductors. An expendable carbon cathode is used to prevent carbon accumulation on this electrode, and a mechanical scraper is used to remove carbon accumulating on a copper anode.

"The arc is rotated magnetically at a sufficiently high rate that a continuous plasma is approached. The interaction of magnetic field strength on the arc voltage demand is optimized to provide the necessary arc stability without excessive power requirements. The electrical power requirement for the arc reactor is 3.0 kilowatt hours per pound of acetylene, including generation of the magnetic field.

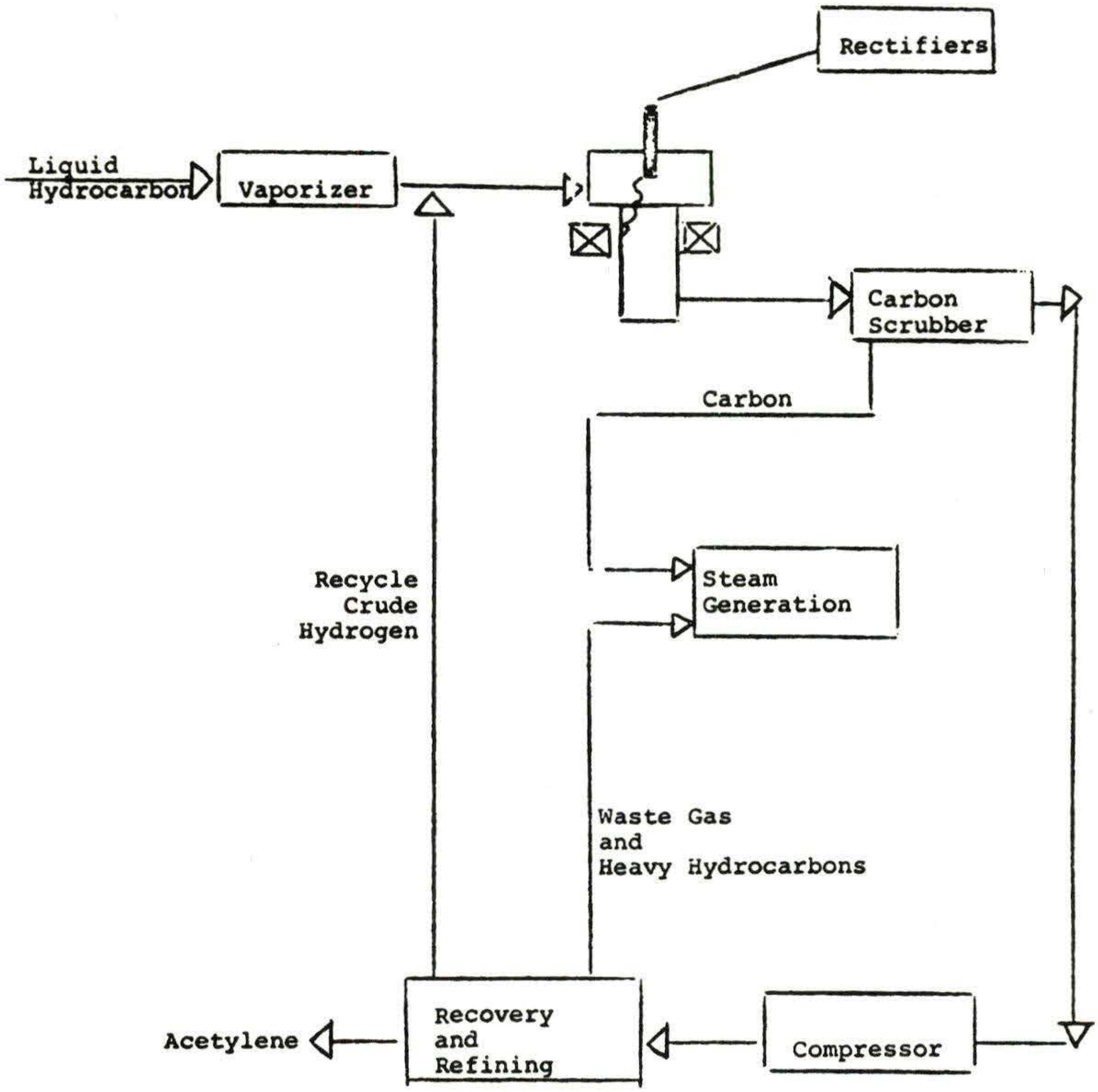
"The arc reactor converts a refinery hydrocarbon cut into acetylene at a yield which is dependent on the chain length of the hydrocarbon. The yield values used here are

$$\frac{\text{lbs. acetylene produced}}{\text{lbs. hydrocarbon fed}} \times \frac{\%\text{C in acetylene}}{\%\text{C in hydrocarbon fed}} .$$

The best chemical yield, 75%, is achieved with butane. As the chain length increases, the yield is reduced to 65% when feeding a hydrocarbon averaging ten carbon atoms in length. Some improvement in yield can be achieved at the expense of additional cost for electricity. The process has demonstrated flexibility at pilot-plant scale for using methane feed, although the plant-scale operation has been limited to liquified petroleum gas or liquid hydrocarbon distillates.

DU PONT ARC ACETYLENE PROCESS

(Figure 3)



"These yields are achieved by operating the reactor at 200 mm Hg absolute pressure and with dilution using a recycled crude hydrogen stream, such that the ratio of hydrogen atoms to carbon atoms in the feed mixture is approximately four to one. Variations in yield are obtainable by modifying the operating pressure or dilution ratio.

"Table 1 describes the reactor product gas analysis after water scrubbing to remove carbon. While the reported values are obtained with a C_{10} feed, essentially the same values apply for butane feed. Higher acetylene concentrations and lower ethylene concentrations can be achieved with minor variations in recycle hydrogen dilution rates and/or electrical input to the arc reactor.

"The high concentration of acetylene in the reactor off-gas means that the facilities to remove carbon and purify the acetylene are relatively small in size. The carbon-water slurry from the scrubbing step is contacted with fuel oil and decanted to give a carbon-oil slurry suitable for combustion. The acetylene recovery system involves a dual solvent treatment using dimethylformamide and oil. Careful attention to the polymerization of heavy acetylenes, such as triacetylene, is necessary before an operable refining system can be achieved. The overall purity of the acetylene produced in this refining system is 99% with small quantities of various impurities. The DuPont refining system has been tailored specifically to minimize reactive materials in our neoprene synthesis process. Inert materials have been removed only to economic limits.

"Dimethylformamide has proved to be an admirable solvent for this service by virtue of its recognized high capacity for acetylene solubility and its unusual selectivity for acetylene in the presence of the other reactor off-gas components. Control of corrosion and solvent stability has been easily achieved through maintaining low water concentration in the dimethylformamide. Solvent losses amount to 0.005 lbs per pound of acetylene.

"The economic importance of this process is dependent on hydrocarbon price and electricity cost. The high chemical yields and high acetylene concentration in the reactor gas make this process compare favorably with other hydrocarbon-based routes to acetylene. Electrical consumption

Table 1

DuPont Arc Reactor Gas

	Vol %
Hydrogen	74.5
Oxygen	0.06
Nitrogen	0.5
Carbon monoxide	0.5
Carbon dioxide	0.01
Methane	4.7
Acetylene	15.2
Ethylene	3.0
Ethane	0.01
Methyl acetylene	0.2
Allene	0.04
Propylene	0.2
Propane	0.01
Diacetylene	0.7
Butadiene	0.08
Benzene	0.25
Triacetylene	0.02
Phenylacetylene	0.02

The above analysis is reported on a water-free basis for a sample taken after carbon scrubbing. This scrubbing step removed 0.04 pounds elemental carbon and 0.10 pounds hydrocarbon oils per pound of acetylene when using a C_{10} feed. Carbon is reduced to 0.02 pounds and hydrocarbon oils are eliminated when using butane feed.

is substantially less than for acetylene from calcium carbide. The fuel value of the by-product materials is adequate for steam generation to supply the internal demands of the acetylene recovery process in addition to some excess for external use by the acetylene consumer. The magnitude of the excess steam is a function of the engineering choice made in selection of compressor drives, etc., in order to obtain optimum overall power balance for each specific installation.

"In summary, the DuPont arc acetylene process has been developed to produce commercial quantities of acetylene from various liquid hydrocarbons using a magnetically rotated direct-current electric arc. Recovery and purification of the acetylene is economically achieved using dimethylformamide as a refining solvent." Additional information on the details of the arc furnace are given in the Appendix.

3.2 Hydrogen By-product

Additional process information obtained from DuPont[7,8] disclosed the following:

The waste gas from the recovery operation could be used as a source of hydrogen for the production of nitrogenous fertilizers. This stream would have approximately the following analysis and would have to be refined further before it could be used for ammonia synthesis:

Component	mol%
H_2	89.5
CH_4	5.7
C_2H_4	3.6
CO	0.6
N_2	0.6
	100.0

The cost of cleanup can be roughly estimated at 1-3¢ per thousand standard cubic feet based on information published by McClelland.[9] The 1¢ per MSCF price would be for large volumes of feed gas (500 x 10^6 MSCFD).

I have estimated the amount of hydrogen available to be about 0.17 ton H_2 per ton of acetylene produced. If this value is not substantially reduced by other losses in the cleanup system, it would be possible to produce about 0.96 ton of NH_3 per ton of acetylene. Thus a 50 x 10^6-lb/yr acetylene plant could be coupled with a 69-ton/day ammonia plant and a 500 x 10^6-lb/yr plant could feed a 690-ton/day ammonia plant (see Table 2). The latter plant would be considered very large in terms of present day acetylene plants but only medium sized in terms of modern ethylene plants (1 x 10^9-lb/yr plants now under construction).

Table 2

Size Relationships for Acetylene-Vinyl Chloride Plants

Acetylene Plant - C_2H_2 ton/day	Acetylene Plant - C_2H_2 lb/yr	Vinyl Chloride Plant ton/day	Vinyl Chloride Plant lb/yr	Ammonia Plant ton/day	Power Consumption Arc Process[a] Mw(e)
72	50 x 10^6	164	114 x 10^6	69	18
144	100 x 10^6	328	228 x 10^6	138	36
721	500 x 10^6	1639	1135 x 10^6	690	180

[a] Does not include power for acetylene recovery system.

3.3 Rectifiers

Mercury arc rectifiers were specified at the time of plant construction because large silicon rectifier units were not available on the market. However, considerable capital cost savings could be achieved with silicon rectifiers and they have been found to operate satisfactorily in this service. The capital costs in Section 4 assume installation of silicon rectifiers.

3.4 Methane Feedstock

Equimolar quantities of acetylene and ethylene can be produced by adjustment of the power input to the arc, but the operating conditions were not disclosed. Also, natural gas has been used as the feedstock in pilot plant tests. A yield of 70% for acetylene from methane was achieved at a power consumption estimated at 4.0 kwhr/lb of acetylene for a commercial size reactor. More by-product hydrogen would be produced in accordance with the higher carbon-to-hydrogen ratio. Information on the production of equimolar quantities of acetylene and ethylene from methane is not available because it has not been investigated.

3.5 Off-Peak Power Operation

DuPont claims that the process could be operated to some extent on off-peak power. If the arc reactors were designed for operation during off-peak power periods, they could be adjusted to approximately 70% of capacity during periods when normal power rates were in effect. Redesign of the transformers might permit operation at as low as 50% of design capacity since reducing the power to the arcs involves a reduction in current and an increase in voltage demand. This is a characteristic of the electric arc system.

Power interruptions have not been a major problem in operating the plant. The arcs cut off on a voltage dip, and the feed system is automatically shut down. However, the arcs require only 10 seconds for restarting.

Storage of large quantities of acetylene as a liquid or as a gas under pressure would be extremely hazardous. Storage at atmospheric pressure (gas holders) or dissolved in a solvent is feasible but expensive for large quantities. Therefore, for off-peak operation, plants downstream of the acetylene plant would probably have to be sized for the peak loads from the arc process.

3.6 By-product Carbon

The by-product carbon produced by the arc process is a heterogeneous mixture of particles which range from finely divided to clinkers. The carbon is quite adsorptive and contains some of the heavier hydrocarbons produced by the arc. Consideration has been given to possible industrial uses for this carbon but its purity and size variation make it unsuitable. However, credit can be taken for its fuel value when burned in a furnace. In this study no by-product carbon credit has been assumed.

3.7 Process Scale-Up

In the Montague plant, two arcs in parallel were used for the 50×10^6-lb/yr acetylene production rate. In scaling up the plant it is estimated that each arc reactor could be doubled in size (20 Mw/arc) by increasing the anode to cathode distance. This would involve the use of higher voltages (perhaps 6000 volts) which would require heavier electrical insulation and greater personnel hazards, but it does not appear to be an unreasonable extrapolation of their present technology.

Approximately 40% of the capital costs given in Section 4. are for the arc reactors, feed vaporizers, electrical equipment and the carbon scrubber. The remainder of the capital is in the recovery system and the auxiliary equipment including the steam generators. A scale-up factor of 0.8 was assumed for the feed system and 0.6 for the product recovery system. Factors actually used are given in Section 4.0.

4.0 PROCESS ECONOMICS

To evaluate the economics of the arc process acetylene route it is not only necessary to determine production costs for acetylene but costing of a high volume intermediate product such as vinyl chloride monomer must be made since acetylene cannot be shipped. A competing process producing the same end product is then used for evaluation. The competing process chosen for this evaluation is vinyl chloride production using ethylene and chlorine via the oxychlorination (OHC) route. Figure 4 is a schematic of the OHC process. A portion of the ethylene feed is chlorinated to form ethylene dichloride (EDC) which is then pyrolyzed to vinyl chloride and HCl. The HCl is then reacted with the remaining ethylene in the presence of oxygen to form more ethylene dichloride and water. This EDC is also pyrolyzed to vinyl chloride. Most new vinyl chloride plants use this process because of abundant supplies of low cost ethylene and the absence of HCl by-product from the process. Data presented recently[4] indicate that if ethylene is priced at 3¢ per pound, acetylene must be no greater than 5¢ per pound if it is to compete in the manufacture of vinyl chloride monomer. The production cost of vinyl chloride in a 100,000-ton/year plant was estimated at about 4.8¢/lb of monomer.

The basic assumptions used in the cost analysis for the DuPont process are presented in Table 3. Data for the economics of the oxychlorination process were obtained from several literature

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OXYHYDROCHLORINATION ROUTE BASED ON CHLORINE

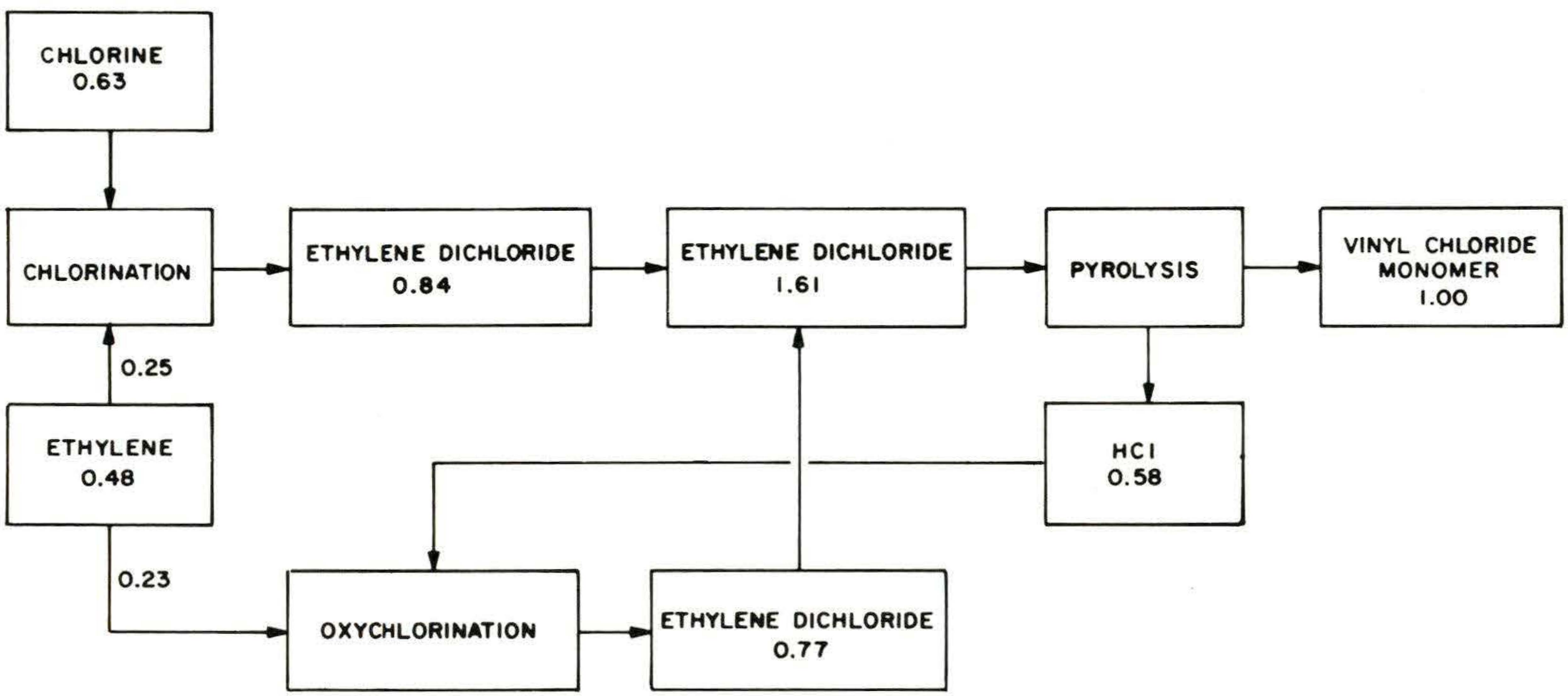

Fig. 4, VINYL CHLORIDE PRODUCTION-WEIGHT MATERIAL BALANCE

Table 3

Basic Assumptions - DuPont Arc Process

I. Base Plant Size = 50 x 10^6 lb/yr or 72.1 ton/day C_2H_2 at 95% efficiency.

Plant Cost (including offsites)

	Capital Cost $ x 10^6	Scaling Factor
Feed System	2.5	0.8
Recovery System	3.5	0.6
Power Conditioning	0.5	0.9
Offsites	1.0	(15.4% of Battery Limits Cost)
Total	7.5	

Overall Scaling Factor = .71

II. Raw Materials and Utilities/Ton C_2H_2

Naphtha - 1.69 ton/ton at $15.00/ton
Power - 6000 Kwhr/ton at 1-8 mills/Kwhr
Exhaust Steam (260°F) - 13. x 10^6 Btu/ton
Prime Steam (540°F) - 27.4 x 10^6 Btu/ton
Cooling water - 100,000 gal/ton

III. Materials

Catalyst and Chemicals -
Solvent Loss = 0.005 lb/lb C_2H_2
Cost at $.30/lb = $3.0/ton
Supplies = 5% of Labor
Maintenance = 3% Invest/year

IV. Labor

Operators = 5 men/shift at $3/hr
Maintenance Labor = 100% Operating Labor or 2% Invest.
Operating Supervision = 10% Operating Labor

V. Overhead = 60% of Labor

VI. Byproduct Hydrogen

a) Hydrogen in Furnace Effluent: = 14.9 mol H_2/mol C_2H_2

b) Hydrogen Required for Fuel: = 4 atoms H/Atom C = 2 moles H_2 atom C

Naphtha contains 84 wt% C and the process requires 1.69 ton Naphtha per ton of C_2H_2.

Moles H_2 required/mole C_2H_2:

$$= \frac{2 \text{ moles } H_2}{\text{Atom C}} \times \frac{1.69 \text{ ton Naphtha} \times .84}{\text{For } C_2H_2} \times \frac{26.04}{12}$$

$$= 6.15 \frac{\text{moles } H_2}{\text{mole } C_2H_2}$$

c) Hydrogen content of Naphtha: Naphtha contains 15.97 wt % hydrogen moles H_2 in Naphtha/mole C_2H_2

$$= \frac{1.69 \text{ ton Naphtha}}{\text{ton } C_2H_2} \times .1597 \times \frac{26.04}{2.016} = 3.49 \frac{\text{moles } H_2}{\text{mole } C_2H_2}$$

d) Excess Hydrogen Available:

$$\text{Hydrogen makeup} = 6.15 - 3.49 = \frac{\text{moles}}{\text{mole } C_2H_2}$$

$$\text{Excess Hydrogen} = 4.9 - 2.66 = \frac{\text{moles } H_2}{\text{mole } C_2H_2}$$

$$\text{Ton } H_2/\text{ton } C_2H_2 = 2.24 \times \frac{2.016}{26.04} = 0.173$$

e) Value of Hydrogen Byproduct:

Assume \$75.00/ton H_2 (20¢/MSCF H_2)

$$\text{Hydrogen Credit} = 75.00 \times 0.173 = \frac{\$12.97}{\text{ton } C_2H_2}$$

sources.[4, 12-14] Ethylene prices are used as a parameter since its actual price is a function of the by-product values for pyrolysis gasoline, butanes, butadiene, propylene and fuel gas. The range used was 2.5 to 3.2¢/lb with the lower value as typical for producing areas, The range of product value was taken as 4.0 to 4.75¢/lb. The lower price may be a negotiated price for a long term contract (10 yrs) whereas the upper is a current F.O.B. plant value for spot purchases.

Results of the building block calculations for the two processes are shown in Figure 5 and the manufacturing costs for acetylene are shown in Figure 6. Parameters selected for the standard case are:

Capacity - 328 tons/day vinyl chloride monomer (100×10^6 lb/yr acetylene)

Cost of Money - 10%

Ethylene Cost - 2.8¢/lb.

Figure 5a shows the effect of the money on the break-even power costs (BPC). For the standard case it is 5 mills/kwhr. Lowering the cost of money to 5% increases the BPC to 6 mills/kwhr and it decreases to 3.2 mills/kwhr for a 20% cost of money. Increasing the capacity to 1639 tons/day improves the BPC to 6.7 mills/kwhr and decreasing the capacity by a factor of two (164 tons/day which would be capable of processing the acetylene output from the Montague Plant) decreases the BPC to 3.5 mills/kwhr. A 0.3¢/lb change in ethylene cost is comparable to a 1.0 mill/kwhr change in BPC so reducing the ethylene cost to 2.5¢/lb (suggested as a reasonable price for producing areas) gives a BPC of about 4 mills/kwhr. Since this is in the vicinity of quoted power prices for large power consumers in Puerto Rico, it appears that the arc process may hold promise for this location.

The right hand margin of Fig. 5 shows the range of current vinyl chloride (VC) prices. It appears that power prices less than 5 mills/kwhr would be required for the standard case if a market price of 4.75¢/lb of VC could be maintained. If the market price drops to 4.0¢/lb VC the power price would have to be less than 2.7 mills/kwhr. However, for a 1639-ton/day vinyl chloride plant, a power price of 3.8 mills/kwhr would be competitive for this market. In the smaller plant (164 ton/day VC) power prices would have to be less than 3 mills/kwhr.

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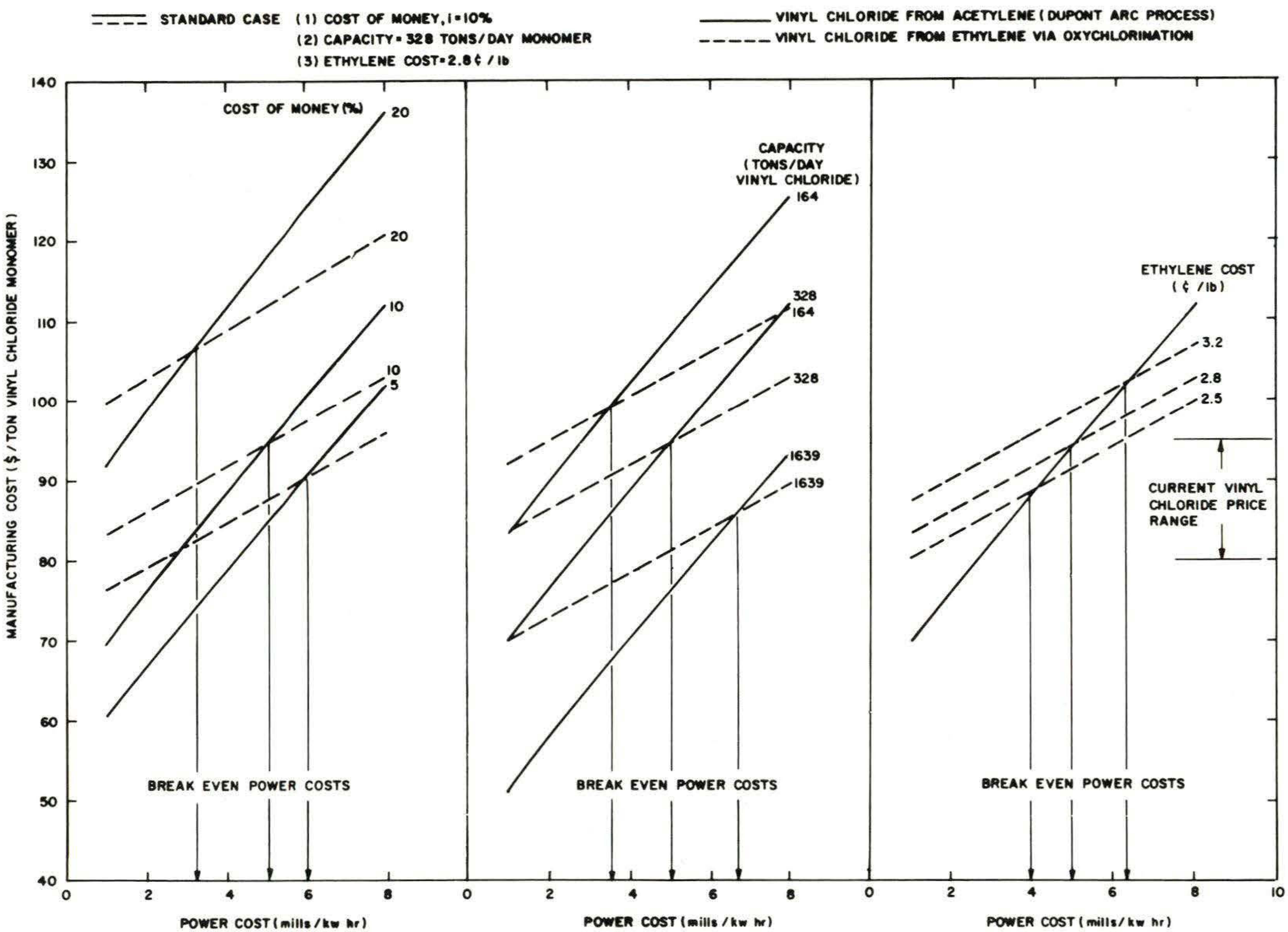

Fig. 5a, EFFECT OF COST OF MONEY

Fig. 5b, EFFECT OF CAPACITY

Fig. 5c, EFFECT OF ETHYLENE COST

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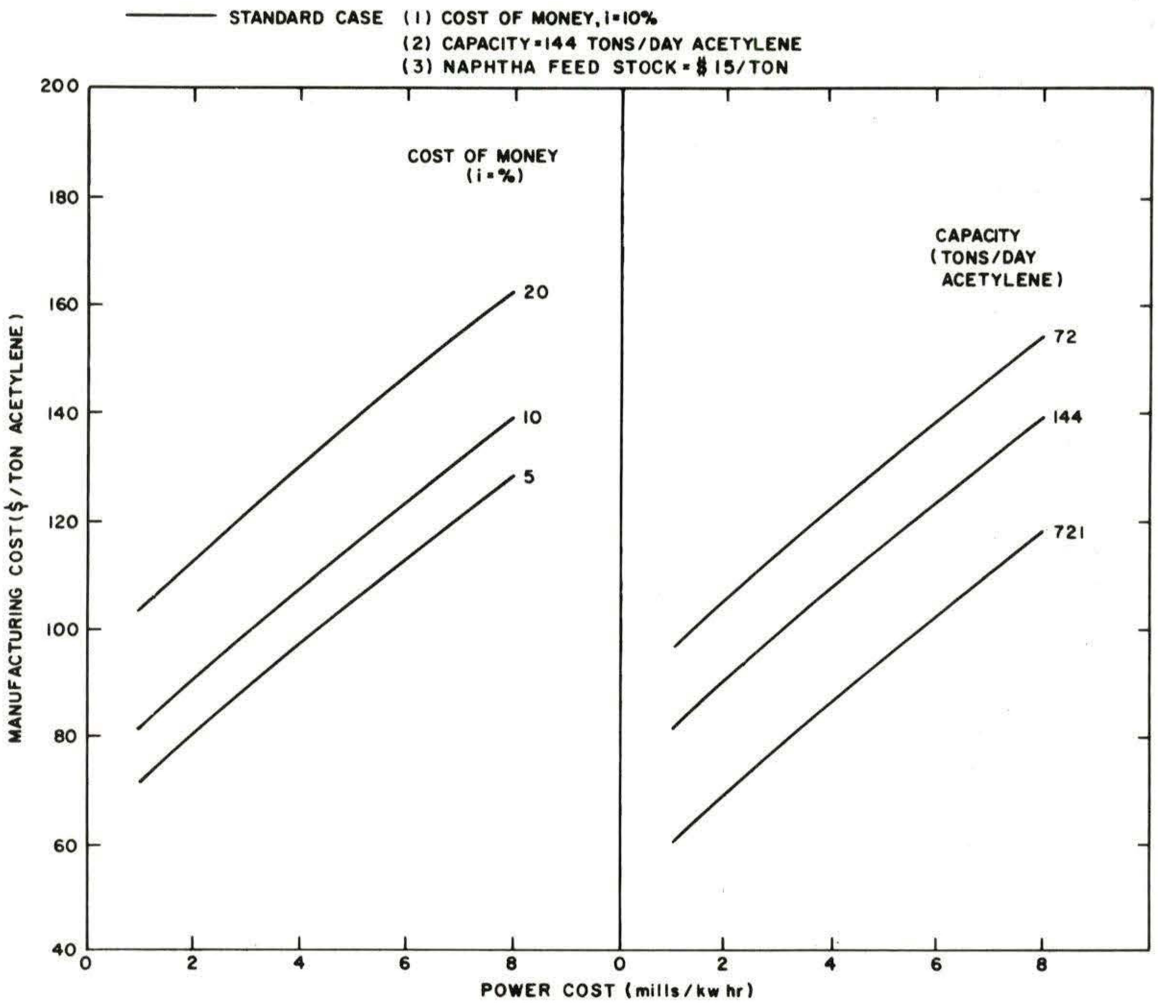


Fig.6a, EFFECT OF COST OF MONEY

Fig.6b, EFFECT OF CAPACITY

Fig.6, MANUFACTURING COST FOR ACETYLENE-DU PONT ARC PROCESS.

Figure 6 shows the manufacturing costs for acetylene. For the standard case (144 tons/day acetylene, cost of money i = 10%) the cost is about 5.4¢/lb for power at 4.1 mills/kwhr. Increasing the plant size by a factor of 5 decreases this to 4.3¢/lb. These acetylene costs include a credit for by-product hydrogen at 20 cents per 1000 std. cubic feet of hydrogen. This credit is believed to be well below the production costs for hydrogen when naphtha is priced at $15.00 per ton. The data from Figures 5 and 6 indicate that ethylene priced at 2.8¢/lb is comparable to acetylene at about 5.8¢/lb (Standard Case) which is somewhat more optimistic than the data presented by Caudle[4] where 3¢/lb ethylene was comparable to 5¢/lb acetylene. However, these comparisons differ considerably in fixed cost bases.

5.0 SUMMARY AND CONCLUSIONS

In developing countries where the petrochemical industries tend to be small, the production of arc process acetylene may be attractive, because the only by-product of value is hydrogen which is readily burned or used for ammonia synthesis. Synthesis of the major competing intermediate, ethylene, requires that large quantities of by-product pyrolysis gasoline, butanes, butadiene, propylene methane and hydrogen be marketed or credited at fuel value. However, power costs must be less than 3 mills/kwhr in order to produce vinyl chloride monomer in small plants (72 tons/day acetylene - 164 tons/day vinyl chloride) at current market prices (4.75¢/lb).

Results of the building block comparison between the use of ethylene and acetylene for manufacturing vinyl chloride monomer indicate that the arc process may have merit if it can be scaled up according to the 0.71 factor used for this study. An arc plant of the Montague, Michigan, size doesn't appear to be economically feasible at power prices greater than 3.0 mills/kwhr. However, if this plant could be doubled in size and demonstrate an efficiency of 95%, it may show promise as an application for nuclear energy centers. Figure 7[4] indicates that a 328-ton/day plant (114,000 t/a) is not unreasonably large when compared with major European expansions currently underway.

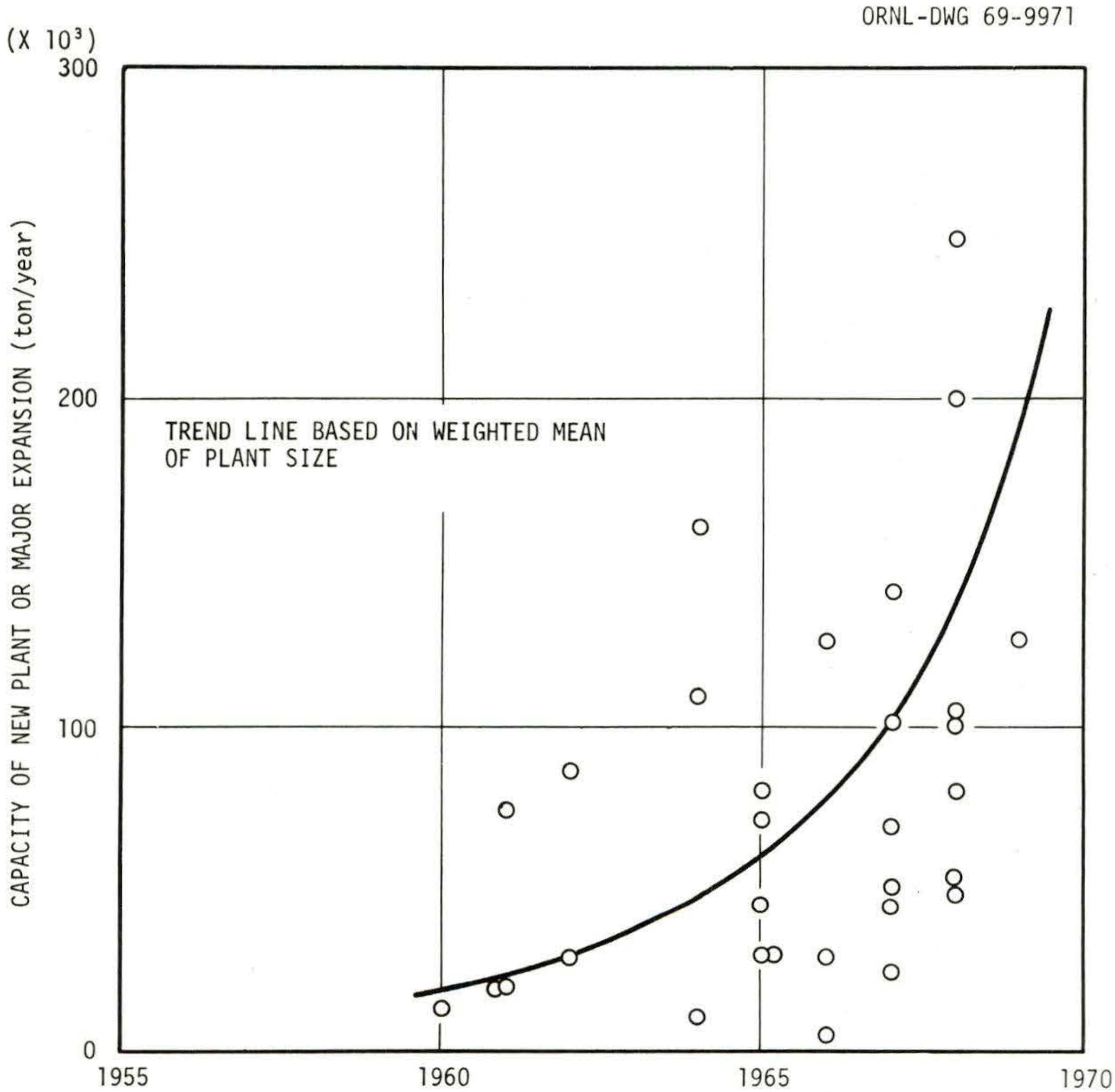


Figure 7. Trend of Vinyl Chloride Plant Size, Western Europe.

Considerable capital cost savings over the Montague plant design might be demonstrated for the following reasons:

1. A higher purity acetylene is required for neoprene than for vinyl chloride, therefore less recovery equipment would be needed for a plant designed to feed a vinyl chloride facility.

2. Improved technology - silicon rectifiers, improved refractories, scale-up of arcs, etc.

3. Shared facilities - steam and water treatment plants and other off-sites could be omitted in a nuclear energy center.

4. A warm weather location may have a significant effect upon the plant design and capital cost.

APPENDIX

Additional information on the arc furnace has been abstracted from the patent literature by Sittig.(15)

"In a two-stage version of the DuPont arc process, a gaseous hydrocarbon containing 1 to 3 carbon atoms is fed to a pre-arc stage and a second gaseous hydrocarbon having a higher molecular weight (but one below 150) is fed to a post-arc stage. The quantity of post-arc hydrocarbon employed must be such that it does not bring the gas temperature down excessively. It should bring the gas temperature down at least 200°C below the temperature of the gas leaving the arc and usually brings it down by 400°C to 900°C. Typical examples of suitable hydrocarbons for use in the post-arc feed include propane, butane, toluene, divinyl acetylene and natural gasoline. The weight ratio of pre-arc feed to post-arc feed may typically be 12.0 to 1.

The cathode spot temperature in the DuPont arc furnace is above 3500°C and approached 4000°C as described by G. Doukas (to DuPont) in U.S. 3,073,769 (January 15, 1963). The gas temperature is maintained above 1700°C and preferably at 2000°C to 2800°C according to M. T. Cichelli and W. Schotte (to DuPont) in U.S. 3,168,592 (Feb. 2, 1965).

When the two-stage version of the DuPont process is used and a second hydro-carbon is fed to a post-arc second stage, that second stage is maintained above 1300°C and preferably above 1600°C to about 2000°C. Finally, it is necessary to effect a water quench to cool the total reaction gases below about 300°C to prevent losses of acetylene by reaction and by polymerization.

The hydrocarbon stream will flow through the arc furnace under a pressure of at least 2 inches of mercury absolute. At present, it appears that the gas pressure usually will be in the range of from 2 to about 16 inches of mercury, and preferably from 2 to about 10 inches. Higher gas pressures may be used, such as those known to the art to be suitable in the manufacture of acetylene by the pyrolysis of hydrocarbons in an electric arc, e.g., up to about 250 pounds per square inch guage.

The residence time from arc to quench is less than 0.01 second and preferably ranges from 0.001 to 0.003 seconds. The reaction medium in the DuPont process is the vapor phase. In a sense the real reaction medium is a rotating electric arc having a frequency of rotation in excess of 2000 revolutions per second. The peripheral speed of such a magnetically-rotated arc may be 3200 ft/sec in a 1.75 inch I.D. reactor in which the arc rotates at 7000 rev/sec. This generates high levels of turbulence which promotes rapid mixing. The arc imparts a high swirling velocity, typically 200 to 400 ft/sec to the arc gas which of course promotes mixing when a second hydrocarbon is added at a post-arc addition point.

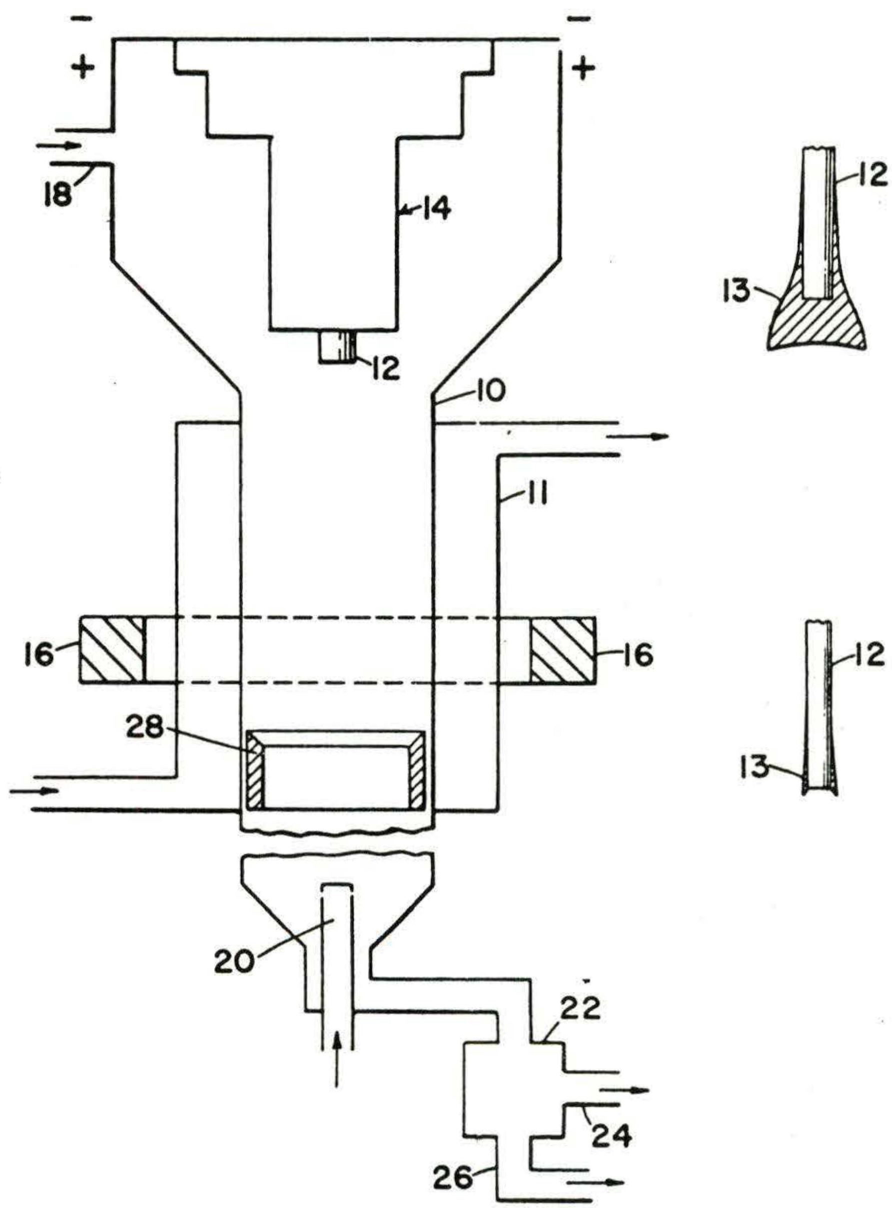
The elements of the DuPont arc furnace have been described by G. Doukas (to DuPont) in U.S. 3,073,769 (January 15, 1963) and are shown in Figure 1A. In that figure, the following designations apply:

(10) Metal shell of arc furnace
(11) Water jacket
(12) Cathode
(13) Deposit formed on cathode tip
(14) Cathode holder
(16) Electromagnet which rotates arc
(18) Hydrocarbon inlet
(20) Water quench spray inlet
(22) Entrainment tank
(24) Reaction product outlet
(26) Separated water discharge
(28) Scraper for carbon removal.

By cooling the cathode holder, 14, and exposing only a short length of cathode to the gas stream, and by regulating the current to control burn-off, deposits are limited to that shown at, 13, in the lower right part of Figure 1A as opposed to the large deposit shown in the upper right part of Figure 1A which is obtained when these controls are not exercised.

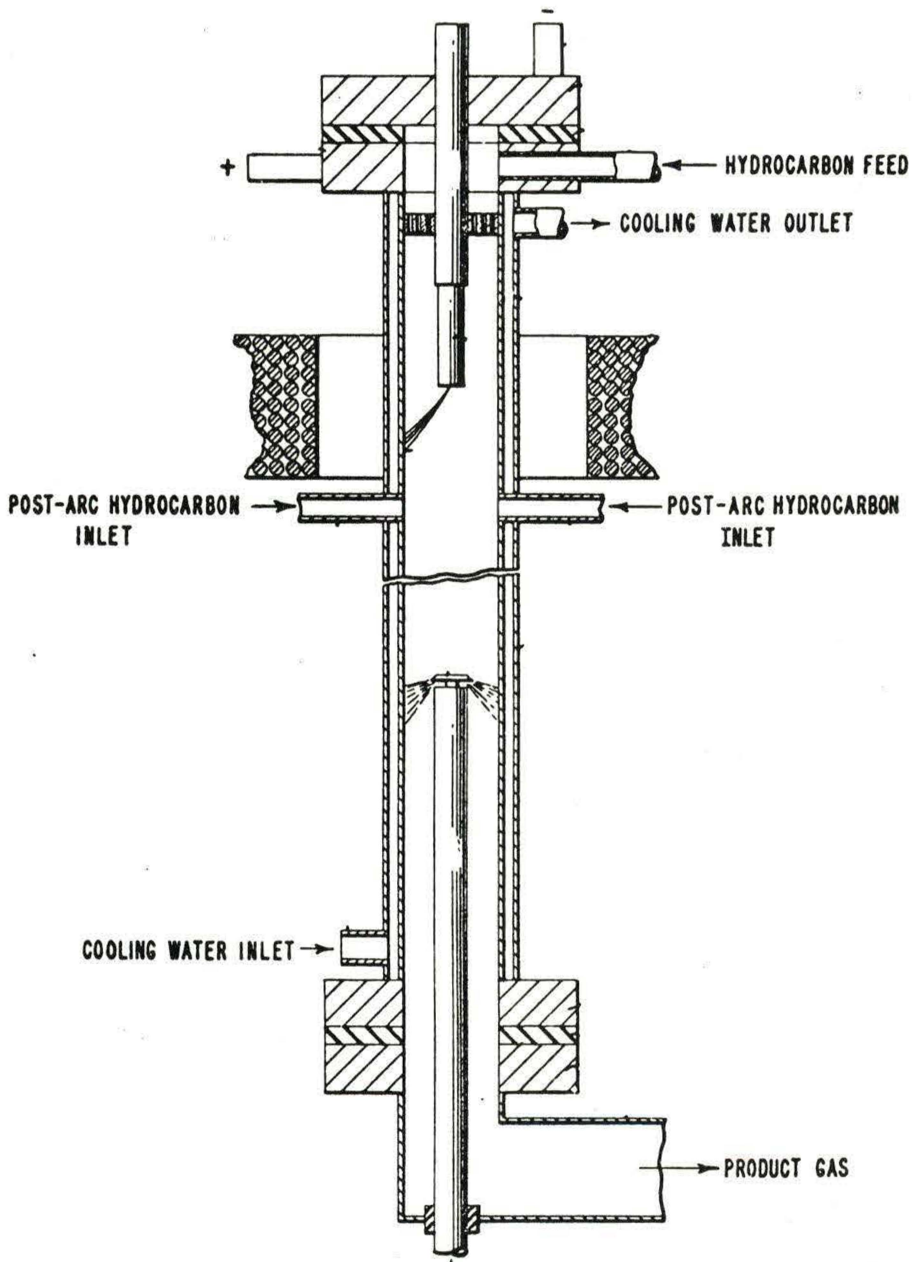
The incorporation of some of these same elements into a two-stage arc furnace are shown in Figure 2A as described by M. T. Cichelli and W. Schotte (to DuPont) in U.S. 3,168,592 (February 2, 1965)."

FIGURE 1a. DU PONT ARC PROCESS REACTOR FOR ACETYLENE MANUFACTURE



Source: U.S. Patent 3,073,769

FIGURE 2a. TWO-STAGE ARC FURNACE FOR ACETYLENE MANUFACTURE



Source: U.S. Patent 3,168,592

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