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ADHESIVES FOR WOOD 1/

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1. Introduction.

An adhesive may be defined as any substance capable of holding materials together by surface attachment. This capability is not necessarily an intrinsic property of the substance which can be a glue, a gum, a binding agent or a cement but it is developed only under certain conditions while interacting with an adherend.

As long ago as 3500 B.C. the ancient Egyptians were known to have used a type of glue to stick decorations onto sycamore wood. Mud, dung and clay were used to build huts in much the same way as unfortunately they are still being used in many parts of the world today.

Many different types of glues have been used throughout the years in the woodworking industry. However, until the early 20th century very little progress was made, the major upheaval in the adhesive industry has been the arrival of synthetic polymers. One of the most remarkable developments in polymer science is the use of adhesives and they are used today in situations which would have been considered impossible some 50 years or so ago. Bonding processes are an established part of production engineering.

2. Classification and description of adhesives for wood.

In general, woodworking adhesives may be divided into two main groups.

2.1. Glues formulated from materials of natural origin e.g. animal, vegetable, casein and blood glues.

2.2. Synthetic resin adhesives which are products of the chemical industry and derived from petroleum, natural gas, coal, air and water.

2.1.1. Animal glue.

Animal glue is usually obtained from the skins and bones of cattle and sheep and may thus be classified as hide and bone glue.

Animal glue may be sold in different forms of which the powder, pearls and jelly are the most common. Different grades are available depending on the method of manufacture and chemical modification. The solid forms may be soaked in water until uniformly soft. They are then melted and owing to the necessity of keeping the glue at the normal working temperature of approximately 60°C. special, heated mechanical glue spreaders are required. Animal glues applied while hot develop their strength first by cooling and gelling and later by drying. The chief disadvantage of animal glues are their low moisture resistance, their relatively high costs and the importance of close temperature control in their application. Animal glues are attacked by moulds and fungi.

2.1.2. Vegetable glues.

The principal constituent of vegetable glue is starch which may be extracted by commercial means from corn, potatoes, rice, sago, tapioca, casava and many other plant sources. These glues are normally sold in powder form and may be mixed with water and other components such as alkalis. Heat is normally applied in their preparation for use. Such mixtures do not deteriorate rapidly and can be kept for several days (long pot life). Vegetable glues are relatively cheap. Their setting mechanism is based on loss of water to the wood and this reaction is relatively slow. In the past vegetable glues were used in such applications as veneering. However, like animal glues the use of vegetable glues is very limited today due to their lack of moisture resistance, staining of certain veneer species and their lack of resistance to attack by micro-organisms.

2.1.3. Casein glues.

Casein glue is prepared from casein curd which is precipitated from milk either by natural souring or by the addition of acids. The glue ready for use is prepared by dissolving the casein in aqueous alkaline solvents to which other chemical ingredients such as formaldehyde or copper chloride are added.

Alternatively, prepared glues may be supplied in powder form which only require the addition of water before use. A number of different casein based glue formulations are available depending on the type of chemical modifications. On the one hand there are glues with a long pot life but relatively poor moisture resistance and on the other hand there are glues with good moisture resistance but a definitely limited pot life. Casein glue may be used as a cold setting glue for the bonding of laminated beams and in furniture construction or for hot pressing of plywood. The moisture resistance of casein glues is superior to vegetable and animal glues but inferior to most synthetic thermosetting adhesives. Disadvantages of casein glues are their tendency to cause staining of wood rich in tannic acid, the dulling effect of the glue lines on tools, their limited moisture resistance and their vulnerability to attack by mould and fungi. Casein glues have become very costly due to the ever increasing demand for protein for nutritional purposes.

2.1.4. Soyabean glue.

Soyabean glue is prepared from either the meal or the isolated vegetable protein. It is similar in composition, properties and characteristics to casein glue. Soyabean glue wood joints may be hot or cold pressed. The moisture resistance is in general somewhat lower than that of casein glue.

Until recently Georgia Pacific Company in the U.S.A. used a casein glue extended with soyabean flour as a binder for particleboard. The novelty of this process was the use of undried wood particles, relying on drying during hot pressing. A similar process was in use for the manufacture of plywood with green veneer. The particleboard was claimed to have low swelling properties and was used as "sidings". For reasons of binder costs the process has been changed to drying the wood first and using phenol formaldehyde resin as binder.

2.1.5. Blood albumen glue.

Dried, soluble blood powder is prepared from fresh blood by evaporation of the serum. Blood albumen glue may be made from the dried soluble blood powder and water. Albumen in combination with various chemicals is still being used in some parts of the world to bond plywood using the hot pressing technique. Prior to the introduction of synthetic resin adhesives, blood albumen was the most important water resistant glue available to plywood manufacturers. The glue line shows some resistance to boiling water, it is however liable to attack by micro organisms. To improve the resistance to micro organisms small amounts of phenolic resin or organic preservatives may be added.

2.2. Synthetic resin adhesives.

Various synthetic resins were introduced as woodworking adhesives in the early 1930's. The greatest progress in their development and acceptance on a large scale began during World War II. Their consumption is still increasing.

2.2.1. Thermosetting resin adhesives

A thermosetting adhesive is one that on crosslinking undergoes an irreversible chemical and physical change to become substantially infusible and insoluble. The crosslinking reaction may be initiated by the application of chemicals and/or heat. The most important examples of thermosetting adhesives are derived from urea-, melamine -, phenol-, and resorcinol-formaldehyde. Formaldehyde being the common raw material for all these resins.

2.2.1.1. Urea formaldehyde (UF).

Urea-formaldehyde resins are available in liquid or powder form and are probably the most widely used thermosetting adhesive for wood, particularly for the manufacture of plywood and particleboard. They may be compounded with hardeners (catalysts), fillers and extenders to obtain formulations curing over a wide range of temperatures. from room temperature to about 200°C. Fillers and extenders are added to control flow, viscosity, resin penetration into the wood and to reduce glue line costs. Unmodified urea-resin glue lines are colourless and have a high water and moisture resistance. Extension with farinaceous flours reduce their resistance to moisture and water. Resistance to elevated temperatures and limited outdoor performance can be achieved by the addition of fortifiers such as melamine crystals or melamine-formaldehyde resin.

2.2.1.2. Melamine-Formaldehyde (MF).

Melamine-formaldehyde adhesives are colourless and are used as hot press adhesives. They have considerable resistance to water and heat and are more weather resistant than UF's. Their high cost and high temperature curing requirements limit the use of the straight melamine-formaldehyde resin to a few special applications. Combinations of MF and UF resin are also available. UF resin modification of MF's reduces their cost but with a corresponding reduction in durability. The wet bond strength of melamine-formaldehyde falls between that of plywood made with phenol-formaldehyde and UF adhesives although lying much nearer to that of PF adhesive which is cheaper than the melamine derived adhesive.

2.2.1.3. Phenol-formaldehyde (PF).

PF adhesives are dark reddish and are available as liquids, powders and in film form. Phenol-formaldehyde resins compounded with fillers and accelerators give high bond strength under all conditions of exposure when properly used. Long term weathering tests have proved their ability to withstand most severe conditions without deterioration. The highest specification for plywood and particleboard make the use of phenolic adhesive almost mandatory. PF resin adhesives require hot pressing at 100°C. or higher temperatures.

2.2.1.4. Resorcinol and phenol-resorcinol formaldehyde (RF and PRF).

These adhesives are dark reddish in colour and are generally supplied as liquids to which a filled liquid or powdered hardener (Catalyst) is added prior to use. They cure at temperatures as low as 10°C. RF and PRF's are principally used as special purpose adhesives. They are more expensive than PF's. Adhesive formulations of this type are known to withstand conditions of exposure better than do most timbers. They are rarely used in the manufacture of sheet materials; their major use is as assembly adhesives for wood. They comply with the highest requirements of all specifications, having the reputation for outstanding durability under the most severe conditions and are therefore widely used for bonding laminated beams, container floors and other load bearing structures.

2.2.2. Thermoplastic resin adhesives

Thermoplastic adhesives do not normally undergo any chemical crosslinking during the curing process but remain in a reversible state and soften on subsequent heating. This group comprises polyvinyl acetate resins (PVAc) and hot melt adhesives.

2.2.2.1. Polyvinyl acetate (PVAc)

These are available in a ready-to-use aqueous form, normally as an emulsion, that rapidly sets at room temperature. They adhere well to cellulosic materials. Their temperature and moisture resistance is inferior to those of UF resins. Joints "creep" under sustained loads. Recently two-part formulations have been introduced that have improved resistance to moisture and heat by the inclusion of crosslinking agents.

2.2.2.2. Hot Melts (1).1/

A hot melt adhesive is a thermoplastic, one hundred percent solid material. Application of heat brings the adhesive to the liquid state which regains its solid state and resultant strength by cooling, as contrasted with other adhesives which achieve the solid state through chemical reactions and evaporation or removal of water (solvents). Hot melt adhesives normally used in the woodworking industry are based on ethylene-PVAc copolymers.

2.3. Miscellaneous adhesives.

A number of new types of adhesives are finding some application in wood-gluing, particularly for plywood and particleboard. In general, information on their long-term durability is still very limited.

2.3.1. Tannin based adhesives. (3, 4)

Tannins are polyhydric phenolic extracts from the bark of wattle, quebracho, mimosa, mangroves, Pinus radiata and other timber species. The condensation products of tannins with formaldehyde have been studied for a number of years in e.g. South Africa, Australia and New Zealand with the view to obtaining a suitable adhesive for the wood processing industry, as binder for particleboard, plywood and fibreboard. Tannins have been chosen because of their polyphenolic nature: their properties thus resemble to some extent those of phenol-formaldehyde resin.

1/ The numbers in parentheses refer to works cited in the bibliography, page 2?.

Adhesives based on tannins have to be carefully formulated. The results achieved with tannin based adhesives vary considerably, depending largely on the tree species yielding the tannins and on the method of extraction. In general, fortifying agents such as crystalline resorcinol, or resorcinol-phenol formaldehyde co-condensates are added to achieve boiling water resistance and hence resistance to weathering. The addition of the fortifying agent also depends on the type of timber to be bonded.

In Australia, at least one mill is using an adhesive comprising an alkaline solution of fortified South African tannin extract for the manufacture of "exterior grade" plywood and particleboard. The use of sulphited tannins for the manufacture of particleboard has also been reported.

The present indication is that the price for the basic tannin extract is similar to ordinary phenol but the price difference varies throughout the world. Processing costs for tannin based adhesives are probably higher than for phenol-formaldehyde and in addition certain national plywood and particleboard specifications clearly preclude the use of adhesives other than phenol formaldehyde for the manufacture of "exterior" type boards.

2.3.2. Spent sulphite liquor (SSL) (5, 6, 7, 8.)

Spent sulphite liquor is a by-product of sulphite pulping and a main source of industrial water pollution. Attempts have been made for some time to utilise spent sulphite liquor as an adhesive for wood. Pedersen in his patent describes a method in which the pH of the SSL was adjusted to about 3.0 with citric acid and then blended with wood chips. Raffael and Rauch describe a process in which SSL was mixed with 2 to 6% of acid curing phenol-formaldehyde resin. The Eastern Forest Products Laboratory in Canada suggest that calcium lignosulphonate - a spray dried powder of SSL, when modified with a strong mineral acid such as sulphuric acid could be utilised as a binder for the manufacture of "exterior grade" waferboard.

The attractions of using SSL as a binder in particleboard are :

a) low adhesive costs.
b) very low thickness and surface swelling of the finished particleboard.

However, the following detracting features should be noted :

a) in general, long pressing cycles and in one process additional autoclaving of the boards is necessary.
b) very high board densities (800 kg/cm^3) are necessary to obtain a comparatively low bending strength.
c) sticking of the boards to caul plates, which is believed to be related to the acid content and board density.
d) it is alleged that the SSL bonded boards are more prone to attack by micro-organisms than thermosetting resin containing particleboard.

Processing disadvantages have so far prevented the large scale manufacture of particleboard with SSL as binder.

3. Thermosetting adhesives for plywood and chipboard.

3.1. General

It is difficult to estimate the world consumption of urea-, melamine-, and phenol-formaldehyde resin since statistics on e.g. wood-based panel products are not specific enough. Therefore when estimating the consumption of synthetic resin adhesives for the different countries and the world total it is necessary to make a few assumptions. Based on 1971 FAO Statistics on the production of wood based panels and boards we have :

TABLE I

Synthetic resin adhesive consumption in tons net solids

Country	Plywood	Particleboard	Total
World total	578.500	1,140.400	1,718.900
U.S.A.	258.500	226.380	485.940
Japan	117.440	26.100	143.540
Western Europe	51.920	583.080	634.950

By 1980 the world total consumption is expected to double. The products with which we are concerned here are the amino and phenoplasts that are consumed as adhesives for wood-based panel production. Particleboard and plywood account for most of the resin consumption. Urea formaldehyde resins represent the largest part of the resin consumption particularly for particleboard.

3.2. Raw materials for formaldehyde based resins and their availability.

3.2.1. Urea.

Urea is a white crystalline solid and is the chief nitrogenous product of protein metabolism. It is obtained on the industrial scale by reacting carbon dioxide with ammonia, both products of synthesis gas. This reaction is not as simple as it at first sounds but needs much ingenious work to overcome such problems as corrosion of production equipment. It is estimated that about 10% of the total urea production is used for the manufacture of urea based resins.

3.2.2. Melamine.

Melamine is traditionally manufactured by the conversion of dicyandiamide which in turn is derived from calcium cyanamide. Alternatively, melamine may be produced by dehydrating urea. In the latter reaction only about 50% of the urea used is converted into melamine in the first step.

3.2.3. Phenol.

Phenol is primarily obtained by chemically converting benzene i.e. the conversion of chlorobenzene or cumene. Benzene is derived from treatment of crude oil or coal. Benzene is a very important feed stock for the chemical industry as various derivatives of it are used in such products as :

a) Polyamides e.g. nylon 6, 6.6
b) Styrene - polystyrene
c) Polyesters

d) Epoxy resins

e) Alkyd resins

f) Resorcinol

g) Detergents

h) Dye stuffs

i) Drugs and insecticides.

3.2.4. Formaldehyde (Formalin).

Formaldehyde is the common raw material for most commercially significant thermosetting wood adhesives. It is obtained by oxidising methanol using a silver or metal oxide catalyst. Methanol in turn is derived from natural gas, naphthalene or synthesis gas.

3.2.5. Availability. (9)

Figures I, II, III, IV in the Appendix summarise the various routes from the raw materials to formaldehyde resins. It would suggest that there should be few if any restrictions to the availability of the raw materials, particularly where natural gas or crude oil is readily available. However, it should be remembered that petrochemical plants are so integrated that there is no flexibility whatsoever and thus it is impossible to stop producing any single commodity for the benefit of another. During the last decade, heavy chemical industry's returns on capital have been rather low. The possibility of shortage - even without the oil crisis - arises because there is currently not enough investment in new plants, and new plants that have recently come on stream have failed to reach their anticipated output. The demand has increased to exceed the supply and coupled with this the increased prices for crude oil and to a lesser extent coal have led to the recent sharp price increases in raw materials and hence resins. World prices for the raw materials appear to be dependent on petroleum feedstock prices, as can be seen from figure V in the Appendix. It is estimated that less than 5% of the world's crude oil is at present used in the chemical industry.

Due to the high demand for fertiliser there is at present a world shortage of urea. It is believed that additional urea manufacturing units will come on stream in the near future.

Only about 2½% of methanol production is destined for formaldehyde resin manufacture. The supply and demand for methanol world wide is currently in balance but further capacity is available to meet increased demand.

The shortage of melamine is believed to be due mainly to technical difficulties in processing. The availability of phenol which depends upon petroleum feedstocks will remain uncertain for some time to come. The supply of phenol was aggrevated by recent breakdowns in the plants of two major phenol producers.

Availability and price are closely related and provided realistic resin prices can be achieved it is anticipated that resin manufacturers will be able to bid competitively for their raw materials.

The formaldehyde resin supply and price problem may have some more headaches ahead for us all. In the words of an executive of the oil industry "It should be some small consolation to know that approximately 25 million pounds of phenol are used annually in the production of 35 million pounds of aspirin. It looks like we are going to need every bit of it."

4. <u>Manufacture of thermosetting resins.</u>

The pioneer polymeric material, phenol-formaldehyde (PF) was discovered by Dr. Leo Baekeland around 1909. This was later followed by urea-formaldehyde (UF) resorcinol-formaldehyde (RF) and melamine-formaldehyde (MF). By about 1920 adhesive applications of these products were being considered. By 1940 adhesives based on PF and UF were well established.

The manufacturing methods for formaldehyde based resin adhesives vary according to the raw materials but all reactions follow basically the same principles.

There are, however, many factors that affect the chemical reaction and every manufacturer has his own particular method.

Formalin, an aqueous solution of formaldehyde, is reacted with e.g. urea, phenol or melamine under carefully controlled conditions. The course, the rate of reaction and the properties of the resin are largely determined by the following parameters :

1. Molar ratio of reactants: formaldehyde to urea or phenol.
2. Concentration of reactants.
3. Acidity or alkalinity during the reaction.
4. Reaction temperature.
5. Reaction time.

4.1. Urea formaldehyde (UF).

UF resins used for the manufacture of plywood, veneering and assembly gluing have a molar ratio of 1 urea to 1.5 - 2.2 formaldehyde whilst the molar ratio of contemporary chipboard resins is 1 urea to 1.2 - 1.8 formaldehyde. Lowering the F/U ratio in chipboard resins decreases the likelihood of excessive formaldehyde fumes during particleboard manufacture. Formaldehyde is normally used as an aqueous solution at 36 - 40% concentration. The reaction with urea proceeds in an aqueous phase at a pH of about 5 under reflux. When the appropriate end-point has been reached the polymerisation is stopped by adjusting the pH to a value of between 7 - 8 followed by cooling. In order to produce a resin that has consistent properties the end-point must be carefully determined.

On completion of the polymerisation the concentration of the resin solution is in the order of 40 - 45%. As the resin is too diluted and insufficiently viscous for use as glue a quantity of water is evaporated under vacuum at low temperature in order to increase the resin content to 65 - 70%.

If a resin is required in powder form, this evaporation of water is carried almost to completion by spray drying. Powder resins have the advantage of longer storage life i.e. 12 - 18 months, and are redissolved just prior to use. By contrast at 65 - 70% concentration liquid UF resins at 20°C. are stable for several months.

A simplified, diagrammatic flow sheet for UF resin manufacture may be seen in Figure VI of the Appendix.

4.2. Melamine-formaldehyde (MF).

The manufacture of melamine formaldehyde resin is very similar to that of urea formaldehyde. They are available in liquid and powder form. Aqueous solutions of MF resins are much less stable than UF resins at the same level of solid content concentration.

4.3. Phenol-formaldehyde (PF).

In the reaction of phenol with formaldehyde two different products may be obtained depending on reaction conditions.

a) Resols
b) Novolaks.

As a general rule, a resol is formed when formaldehyde is used in molar excess to phenol under alkaline conditions, while a novolak is obtained when phenol is in molar excess and the reaction is carried out under acidic conditions.

Resols are by far the more important resins for wood gluing. They are usually manufactured with a molar ratio of 1.5 - 2.5 formaldehyde to 1 of phenol. The reaction catalysts during manufacture are normally strong alkalis such as potassium-and sodium hydroxide. In general, the reactions are similar to those described for urea resins.

Resols are available as dark reddish brown liquids or spray dried powder. PF resin solutions of this type are strongly alkaline (pH 12 - 13) in order to obtain a good storage life at a resin solids concentration of between 40 and 50%.

In novolaks the ratio of formaldehyde to phenol is about 0.7 - 0.8 to 1.0

and oxalic or sulphuric acid are common catalysts during resin manufacture. When the desired end-point has been reached novolak syrups are generally run out into large trays and allowed to cool. The resin solidifies and is then ground to a fine powder and mixed with hexamethylene tetramine which acts as formaldehyde donor in the final crosslinking reaction e.g. during hot pressing. In the woodworking industry, novolaks are mainly used for the manufacture of exterior grade waferboard i.e. "Aspenite".

4.4. <u>Setting up plants for the manufacture of resins.</u>

The basic chemical reactions between formaldehyde and urea, phenol and melamine are well documented and large scale synthetic resin manufacture is an established process. Considerable know-how, gained in years of experience, is however involved. Detailed information is usually only available from patent specifications. Established manufacturers of synthetic resin adhesives aim at producing specific grades of resin with consistent quality by the most economical means to meet different but exacting requirements. These are necessitated amongst others by the wide variations in inherent properties of wood and by the different wood conversion processes in use. Therefore a clear understanding of the entire technology, a process that takes years of experience, is essential to meet all the technical requirements.

An adhesive manufacturing industry cannot be started without proper foundation - realistic project reports - as otherwise serious difficulties both as regards the manufacture and marketing of resins may be experienced which will be responsible for disappointment.

Adequate marketing research and a realistic survey of the economic and technical conditions of the area of possible plant location is very necessary and important and should be prepared in the light of local conditions regarding availability of raw materials, costs, skilled labour etc.

Thus, the setting up of a resin manufacturing unit in a market where the requirements are sufficiently large may best be achieved by inviting resin manufacturers with experience -

- to invest directly in the particular country
- to buy the complete resin plant together with manufacturing know-how
- to establish a joint venture with an organisation that has the experience and know-how.

It is difficult to define the minimum economic size of a resin manufacturing unit as this depends on a) availability of and proximity to raw materials, b) expected rate of return on investment, and c) prevailing trade and Government policies. The investments necessary for a resin manufacturing unit, assuming the minimum plant size to be 20,000 tons of liquid UF resin per annum, are estimated to be between £1.0 and £2.0 million (sterling). However under unfavourable conditions a local resin manufacturer may suffer by not having large scale purchasing power, particularly at a time of world wide shortages. Furthermore he may not be in a position to finance expensive reseach and development work for new, more economical resin manufacturing techniques, and on resins with improved performance and efficiency. Finally, the resin user may no longer be able to draw on world wide experience in resin applications offered by most established resin manufacturers.

5. Preparation of the complete adhesive mix.

5.1. For plywood.

A plywood adhesive mix based on one of the synthetic resins mentioned above usually consists of :

1) a liquid or re-constituted powder resin (powder resin dissolved in water).
2) hardeners sometimes also referred to as catalysts or accelerators.
3) fillers and/or extenders.
4) additional water
5) additives e.g. preservatives, fire retardants, anti-foam agents, dyes.

The hardener promotes the setting (curing) of the adhesive mix. In the case of UF or MF resins or blends thereof it can either be an acidic substance or the chemical is capable of liberating acid when mixed with the resin.

In order to achieve a more gradual curing process, i.e. a better ratio of pot life to curing time, the hardener may also contain a retarding chemical e.g. ammonia.

It may sometimes be advantageous to increase the rate of cure of phenolic resins and this is achieved by the addition of an accelerator such as resorcinol or paraformaldehyde.

Fillers and extenders, terms that are used rather loosely, are fine powders of such products as leguminous and farinaceous flours (pea, wheat and rye flour) vegetable starch (tapioca) wood flour, shell flours (coconut shell flour) finely powdered gypsum, chalk and china clay.

The effect of the addition of fillers/extenders is to :

1) Adjust the rheological properties of the adhesive mix e.g. viscosity, cohesiveness, spreadability.
2) Reduce glue line costs.
3) Reduce absorption and penetration of resin into porous wood.

5.2. For particleboard

A suitable binder mix for the manufacture of particleboard may consist of :

1) a liquid or reconstituted powder resin.
2) hardener.
3) wax emulsion.
4) additional water.
5) additives.

Depending on the particleboard manufacturing conditions and on the acidity of the wood a resin may be capable of curing by heat alone, but curing is normally accelerated by the addition of hardener. The hardener may also contain retarding chemicals e.g. ammonium chloride with ammonia.

Emulsions of wax in water may be added to the resin in order to reduce the rate of water absorption by the finished particleboard. Such wax emulsions have to be stable in the resin solution.

Water may be added to obtain the desired resin solids concentration and hence viscosity of the final binder mix suitable for spraying onto the particles. Fire retardants, insecticides and fungicides may also be added via the resin mix. Such additives have to be compatible with the resin and should preferably neither affect the resin curing characteristics nor the mechanical properties of the resultant particleboard.

6. Synthetic resin adhesives and their application.

The selection of adhesives for use in the manufacture of panel products is of the utmost importance since amongst other things their properties influence the characteristics and end usage of the final product. However, the most important property of a cured adhesive is its ability to develop and maintain a good bond strength between the adherends. It is thus the durability of the bond that matters not just the durability of the adhesive itself.

Plywood, blockboard and particleboard used strictly for internal applications such as furniture, need to have a good bond strength but they do not necessarily require moisture or water resistance. On the other hand, wood based panel products used externally and exposed to all climates, such as in housing, require an adhesive capable of withstanding any type of climatic change without fear of breakdown.

Urea formaldehyde resins and their inexpensive extended mixtures have found wide acceptance as adhesives for plywood, blockboard and particleboard. The bonding strength can be varied depending on the degree of modification of the adhesive itself. The addition of filler and extenders may be accompanied by a reduction in bond strength and in extreme cases such as tea chest and interior plywood, adhesives can contain more filler than synthetic resin on a weight basis. In general, melamine formaldehyde adhesives have a limited use in the manufacture of panel products on account of their cost and in terms of performance they have been replaced by phenol formaldehyde. Plywood and particleboard bonded with phenolic adhesive can be used in applications where maximum adhesive durability is an essential part such as in housing. Those adhesives having the potential to yield the highest durability are in general the most expensive and most demanding in terms of application.

The usual spread of adhesive in plywood is between 100 and 250 g/m^2 at a resin solids content of between 30 and 50%. This spread is, however, about 20 to 25 times that considered economically acceptable for particleboard, although the total surface area of the particles is many times greater than in plywood. Adhesive costs in particleboard in fact may comprise from 20 to 50% of the total production costs; in plywood the costs vary between 7 and 20%.

Therefore, durability, cost and convenience must all be carefully considered before any choice is made. The type of thermosetting, synthetic resin adhesives considered here may conveniently be classified in descending order of durability :

Phenol-formaldehyde (PF) which includes resorcinol formaldehyde (RF) and co-condensates.
Melamine-formaldehyde (MF).
Melamine-formaldehyde (MF) containing urea formaldehyde (UF) co-reacted or as physical blend.
Urea-formaldehyde (UF) containing melamine.
Urea-formaldehyde.

In British Standard 1455 August 1972 "Specification for plywood manufactured from tropical hardwoods" four bonding groups are defined. In ascending order of durability these are INT, MR, BR, and WBP. These can be related to chemical groups and environmental conditions as follows:

BS Type	Chemical Type	Environment
INT	UF with high proportion of filler	Indoor - not load bearing
MR	UF with filler	Indoor - load bearing
BR	UF upgraded with melamine or MF resin	As for MR but improved outdoor performance though not permanently durable.
WBP	Phenolics (including resorcinols)	Outdoor unprotected.

Other plywood standards use cyclic tests involving short periods of immersion in boiling water alternated with soaking in cold water and forced drying of the plywood as in German (DIN) and United States Standards.

The table below gives approximate equivalents of various National Standards :

Country and Specification Number	Germany	Japan	U.K.	U.S.A.
	DIN 68705	Export Plywood Standard	BS 1455	CS35-63
Durability category and chemical type of adhesive :				
Most durable phenolic	Type AW-100	Type I	Type WBP	Type I
MF-UF with up to 40% UF	Type AW-100	Type I	-	Type I
Fairly durable UF resin with 15-20% melamine added.	Type A 100	-	Type BR	-
Good water resistance less resistant to prolonged wetting and drying: UF with some filler	Type IW 67	Type II	Type MR	Type II
Resistant to cold water for short periods: Heavily extended UF	Type IF 20	Type III	Type INT	Type III

7. Concluding remarks.

Adhesive formulations are being tailor made and tested to meet wide and exacting requirements. Synthetic adhesives are now recognised engineering materials. New advances will probably be made in adhesive formulations, particularly for exterior plywood and particleboard, but it is difficult to foresee any radical changes in the type of resins used. Some of the existing specifications for plywood and chipboard leave little room for innovation in new adhesives. However, the ever increasing availability of more sophisticated methods in polymer science may lead to providing products designed to satisfy specific needs.

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Figure I SOME RAW MATERIALS FROM COAL

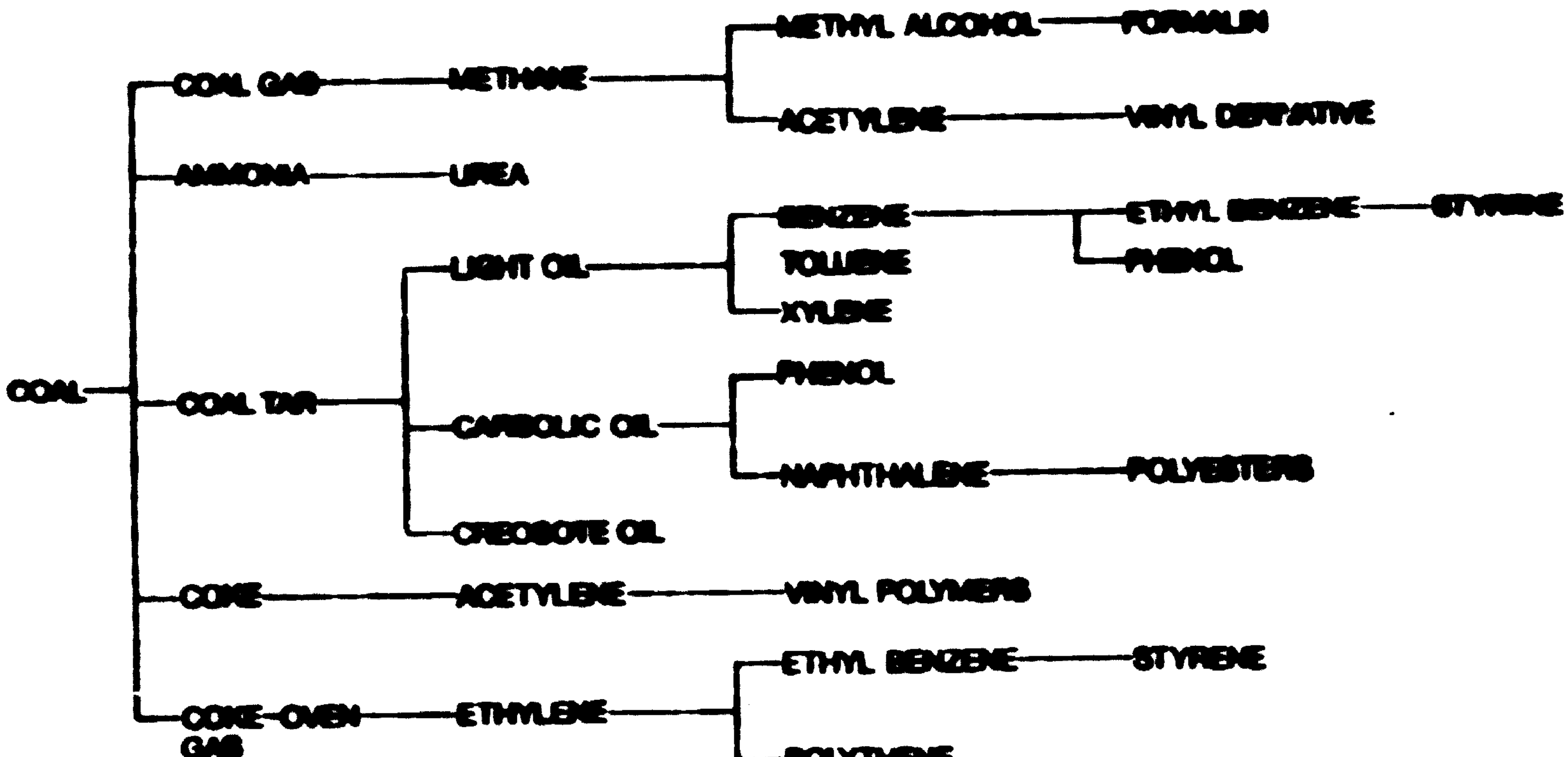


Figure II

SOME RAW MATERIALS FROM CRUDE PETROLEUM

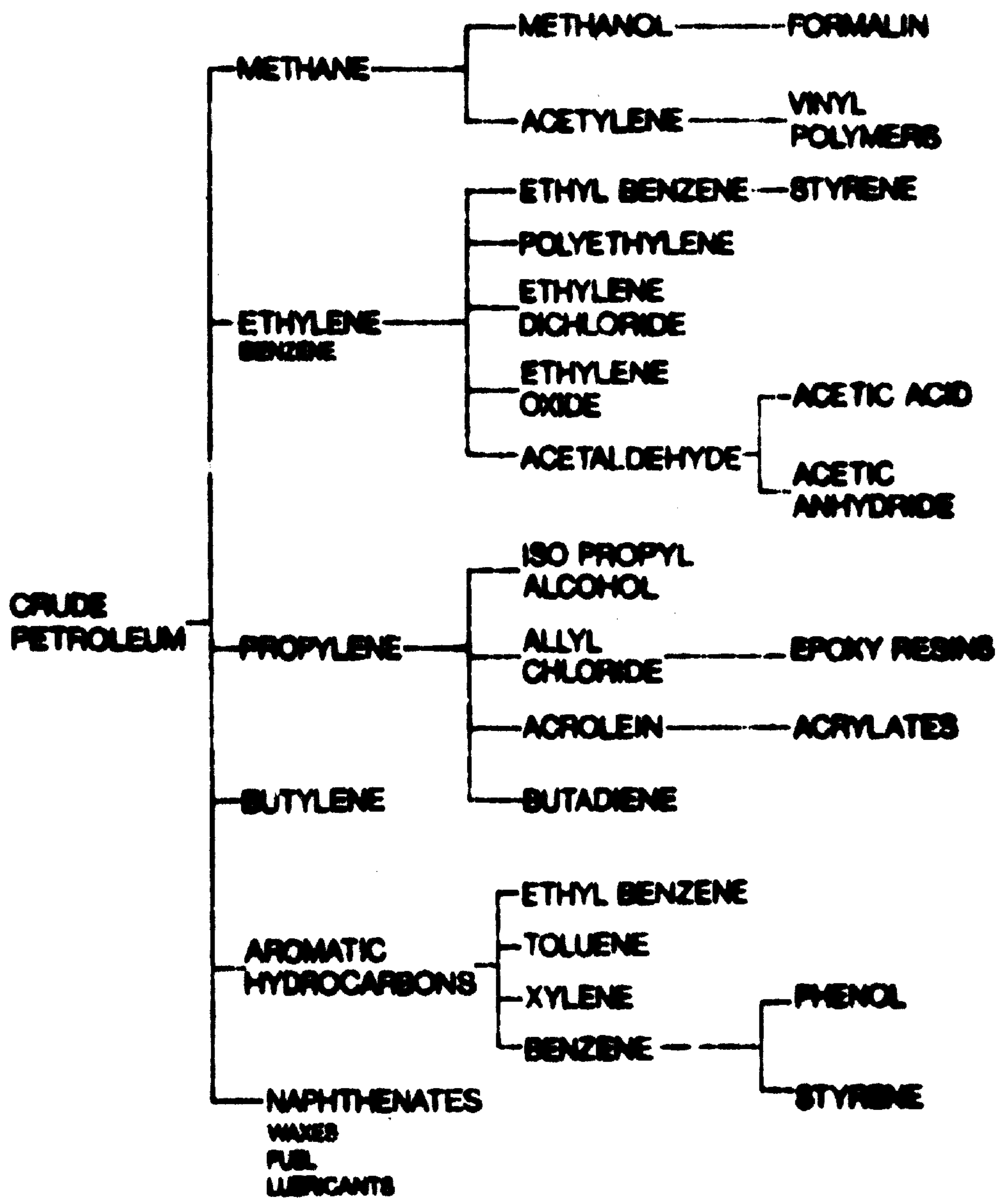


Figure III

FLOW SHEET FOR MANUFACTURE OF UREA & MELAMINE

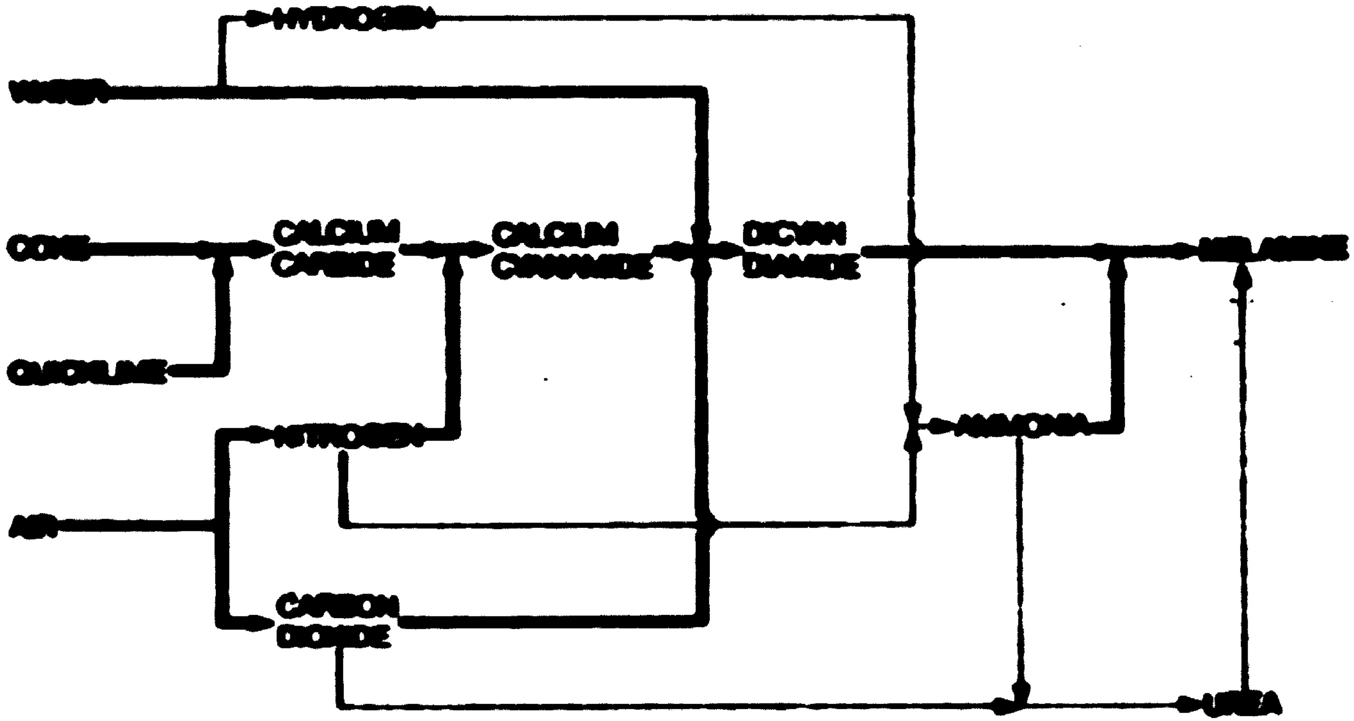
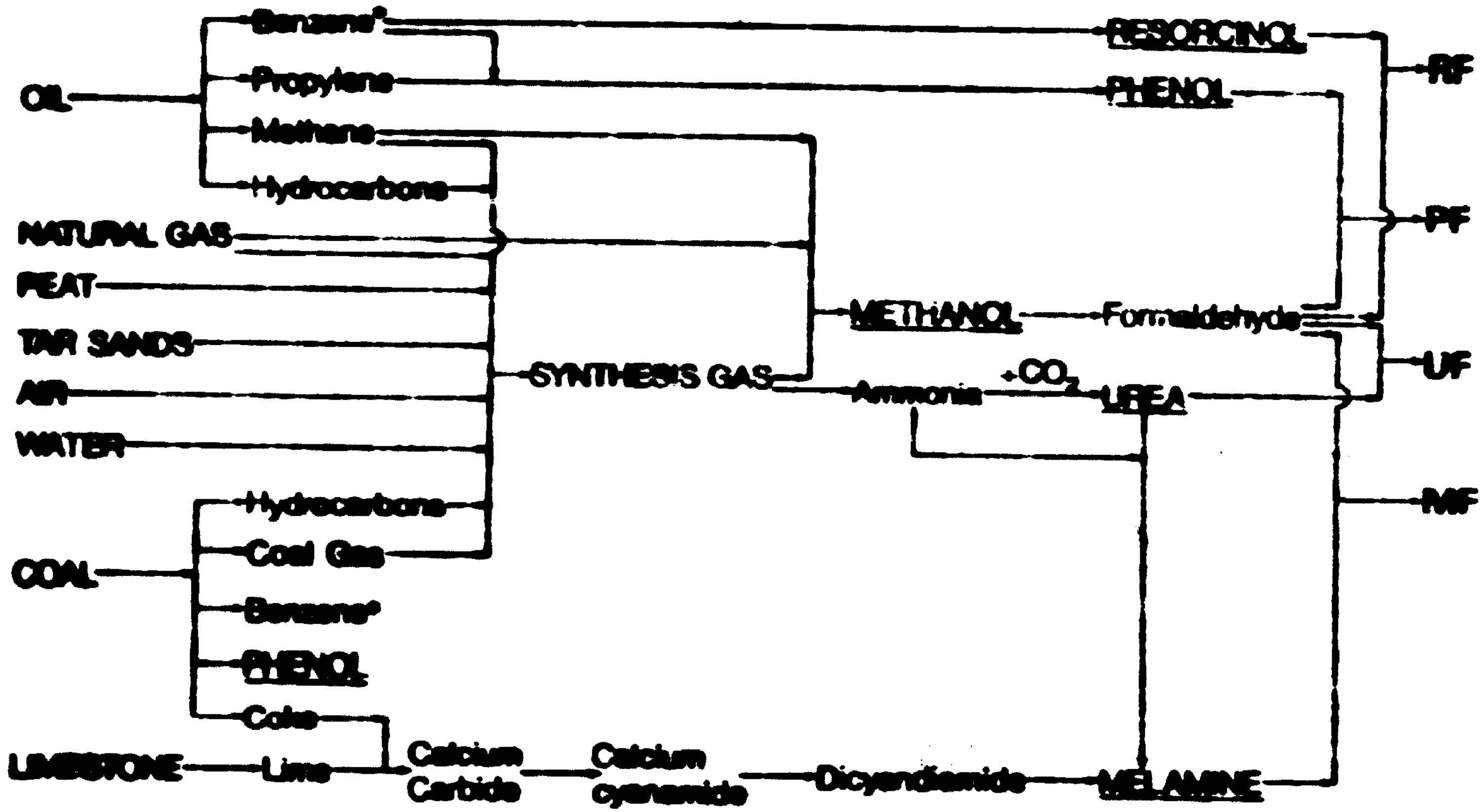


Figure IV SYNTHESIS ROUTES TO FORMALDEHYDE RESINS



Benzene* from either source can be used to produce phenol & resorcinol

Figure V RAW MATERIAL PRICE CHANGES

CHEMICAL MARKETING REPORTER PRICES IN US $/TON

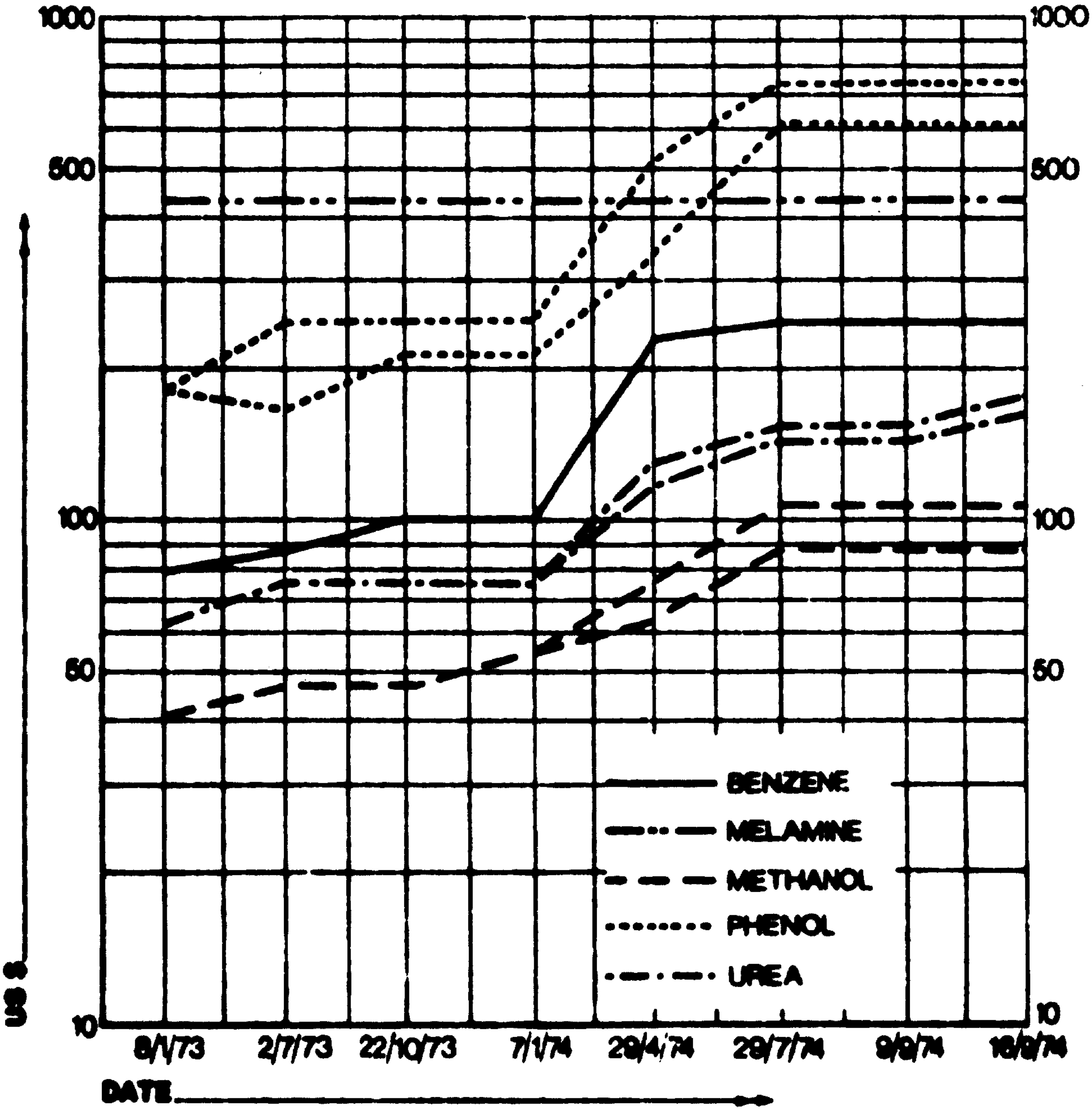
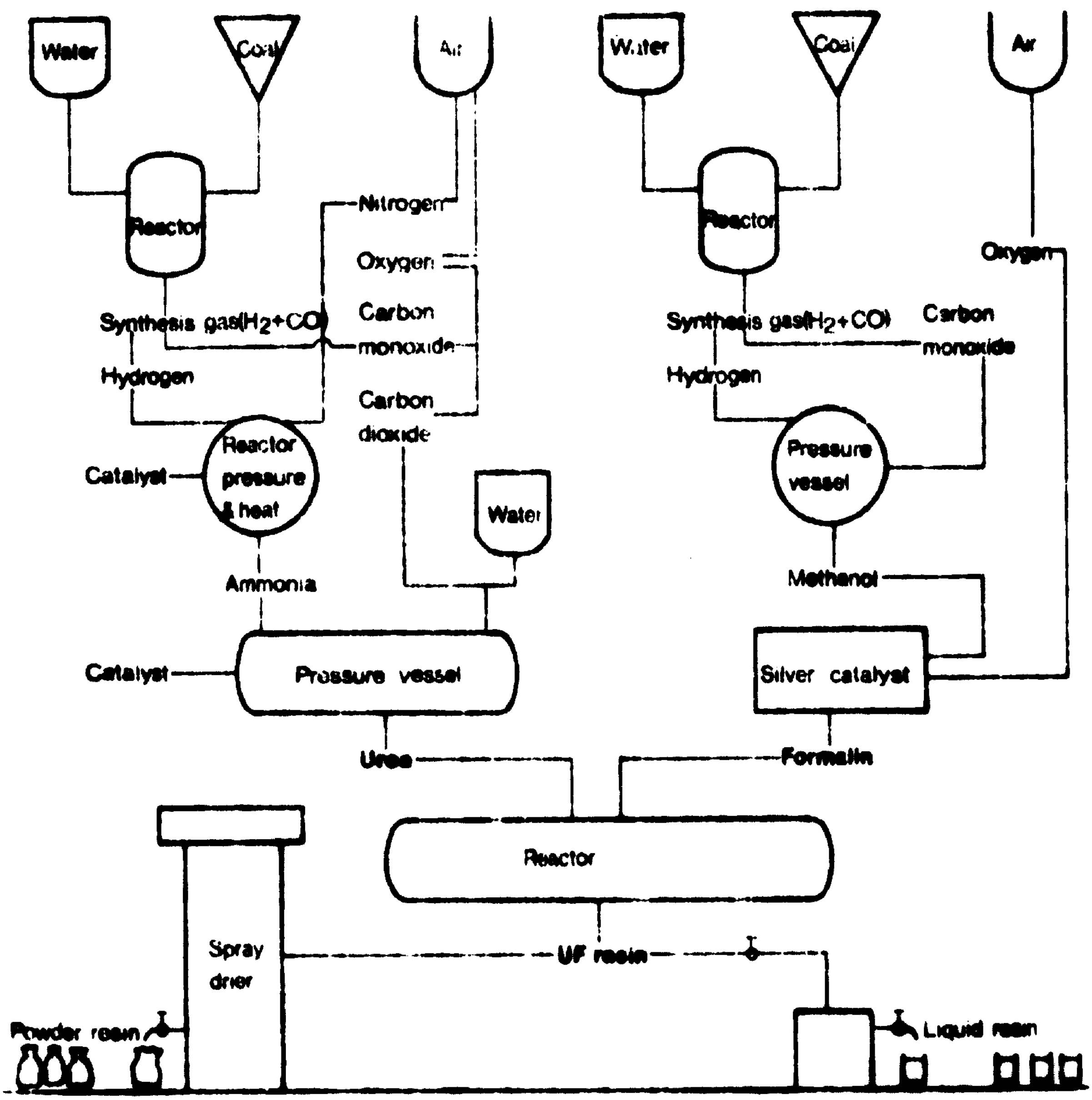


Figure VI PRODUCTION FLOW SHEET FOR THE MANUFACTURE OF UREA FORMALDEHYDE RESIN



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