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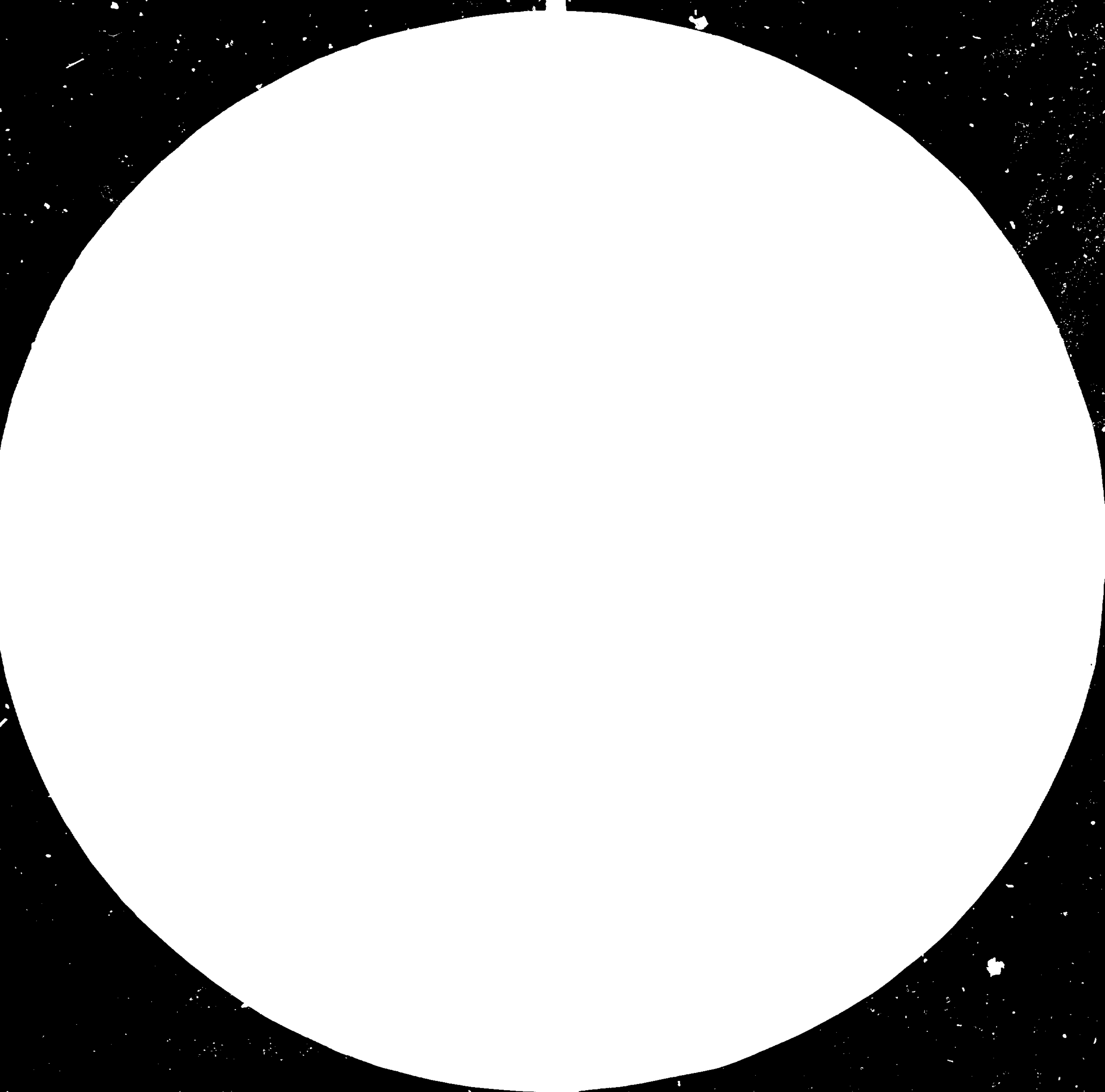

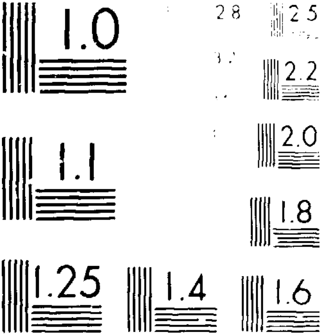
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→ Maria Dietrich

UNIDO - Czechoslovakia Joint Programme
for International Co-operation in the Field of Ceramics,
Building Materials and Non-metallic Minerals Based Industries
Pilsen, Czechoslovakia

Distr.
LIMITED

JP/105/81
October 1981

ORIGINAL: English

Technical Workshop
on Energy Conservation in Silicate Industries
for the Least Developed Countries

Pilsen, Czechoslovakia
5 - 16 October 1981

ENERGY SAVING IN THE GLASS INDUSTRY

/Lecture for the Technical Workshop/

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Energy saving in the glass industry

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Save it - we can hear every day. Save also energy. Save energy in glass. Why? Ten or more years ago the motivation in industry to minimise the use of energy, was primarily one of cost. Process improvements were making rapid strides and have since gathered considerable momentum, but the underlying incentive was the reduction in unit cost. From this point of view energy cost in glass industry is not negligible. The production of the glass uses energy in a number of ways and therefore is necessity of energy conservation activity on all areas, it is concerning light, heat, process and power.

For example the average total direct in-plant energy usage per tonne of glass containers shipped is approx 10 to 18 GJ/t and this can be now over 30 % of total cost.

Melting and forming use on average over 80 % of the glass plant energy requirement, therefore they are the first to be considered, but the rest is not negligible even wi-th the results in saving not so dramatic, and cannot be forgotten.

The weight of energy cost is therefore so important, because the price of primary sources is climbing every year. For example the price index 1970 - 1980 is according next table /Monthly Bulletin of Statistics/

1970 = 100	1975	1979	1980
fuels	609	1036	
oil	646	1214	2040
others	271	291	358
raw materials	540	851	1297
industry products	177	245	

From this table is clear that

1/ The dynamismus of oil price is higher than the dynamismus of other fuels and mainly of the dynamismus of products prices

2/ Similar high dynamismus can be seen in prices of raw materials, partly influenced sure from climbing of oil price, mainly in those materials, in which the energy content is high.

We speak about energy content in glass. Starting speech about this we must give the answer on the question - in comparison with another products and industry branches is glass from energy consumption point of view better or worse and the total energy consumption in glass industry sensible high? Is glass manufacturing so energy intensive how we can read and hear every day?

Again the example from container production:
In next table is energy content in some packaging products of the same size /%/

aluminium can	115
PVC container	103
steel can	78
one way glass bottle	73
steel can cold rolled	52
returnable glass bottle	
with 8 returns	47
with 15 returns	38

In this context it is of interest that for example the packaging glass industry of FGR uses about 500 000 tons of oil per year. As the total consumption of oil in FGR is over 100 million tons per year, only 0,5 % of total goes into the production of glass containers.

It is therefore important to change image of glass industry from that of a high energy consumer to that of an industry which uses only an insignificant amount of total energy. By this is not meaned that glass industry should forget about or neglect energy saving programmes. They are important even from glass cost and therefore competition point of view. But the public should certainly be made aware of the fact that an energy saving of ± 20 % by the glass industry is for example only equivalent to the energy used by motor vehicles in 1 1/2 day. Such a comparison will illustrate how little energy the glass industry actually uses in comparison with other industry branches.

The image of energy intensive industry is also therefore because the glass industry is integrated manufacturing process from raw materials to glass product. For example the manufacturer of plastic packages purchases product - resin from the petrochemical industry with high content of energy, producer of cans buys rolled steel or aluminium with the high energy content from the metal working industry.

But this doesn't mean that energy saving in glass industry is not necessary. And this is necessary not only from product cost point of view but also from energy availability point of view.

The thought that the amount of energy available is limited, and which therefore implied a finite resource, was virtually some years ago unknown and not recognised by industry.

We accept now, that most of the energy that we use is derived from fuels that were laid down in the earth millions of years ago and which, when used, can never be replaced and their supply is finite.

Past production philosophies have usually led to the use of more energy to save time in the quest for higher productivity, whereas in fact the present situation would demand quite the reverse, now we must use less energy to buy time needed to develpp new supply sources but without detriment to output perfotmance.

Since that time, and more recently, industry has been made aware that the rate of energy usage is a controlling factor in the time span of energy availability. Thus governmental pressure and industry's acceptance of its obligations has led to a reappraisal of the fundamental requirements of energy conservation. This has led, in turn, to an examination of those manufacturing units which not only consume energy within the factory but also on the amounts of imported energy associated with the production and delivery mainly of all raw materials and fuels, but also with refractories for example, and on energy consumption associated with product usage /for example for glass containers transport to the bottlers and packer, filling, cap manufacture, transport to the retailer and finaly waste disposal and recycling/.

In this context we should perhaps begin to include in our costings the estimated cost of energy consumed by a product or process over its useful life to arrive at its Total Energy Weighted cost. From this point of view we can look in another light also on glass products, that are used in thermal insulation function as glass in the building industry as windows, panels for outside cladding, fiberglass insulation etc. The thermal transmission of these products is a part of the Total Energy Weighted cost.

No reliable figures appear to be available for all this parts of total energy concept, but it is estimated that it will be at least double the in - plant figure.

It was estimated that without new energy sources up to 40 % is the obvious need to conserve all sources of energy both primary and secondary to close the gap between supply and demand se and so ensure a measure of economic progress over the next 40 years or so.

So in this lecture answering on the question how to save the energy I want to consider not only the direct energy requirement of the glass plant, but also the indirect energy, especially there, where it is connected with production cost, mainly in raw materials and fuels area, considering that it is not only cost problem but also the problem of preserving of energy finite not renewable resources commonly.

For analysis of possible energy saving I want to survey energy consumption in diverse glass production, to refer to some possibilities of energy savings in glass melting area, to consider briefly other parts of the chain of production and at last to occupy myself with methods of energy management.

In all parts I shall try to demonstrate corresponding quantitative relations and values for imagination about possible saving and potential value of this saving.

First of all some words about raw materials and fuels from total energy point of view.

Raw materials

Every raw material requires processing before it becomes suitable for glassmaking. In some cases it may simply involve digging from the ground and transporting to the glass factory. In others, many complex processes may be involved requiring the importation of secondary materials and fuels before preparation can begin. Each subsidiary process requires the expenditure of energy before the total energy associated with the finished raw material can be computed. Each supplier can therefore be looked upon as a factory in itself.

The energy used to manufacture and deliver the subsidiary materials to the supplier is not under the control of the supplier and is called "indirect energy". In addition, energy is used in processing the subsidiary materials to yield the final product. This is under the control of the supplier and is called the "direct energy". Further energy is expended on delivering the product to the glass factory.

There are therefore three elements to consider in assessing the total energy associated with a raw material: indirect energy + direct energy + delivary energy = total energy. In this the delivery energy is a function of the distance from the supplier to the glass factory and the mode of transport.

Table 1 summarises the current energy requirements to produce one tonne of raw material at the supplier. Delivery energy is not included since this will depend on the distance and mode of transport. Examination of Table 1 shows predictably the high energy penalty incurred by the heavily processed synthetic materials. Soda ash, alumina, and selenium are outstanding and for example in the glass container industry successful attempts have been made to contain them. Soda in glasses has been reduced in recent years from about 15 % to 13 % and possibly lower in some cases. This has generally been carried out at the expense of lime which has risen from about 10 % to 12 % and higher, with a consequent reduction in the raw material energy requirements. Similarly, alumina has been replaced by felspar or phonolite and Calumite, and selenium, following the elimination of arsenic, is used in very small amounts which contribute very little to the energy usage.

Relatively new but with use each year increased is supply to the glass industry of beneficiated blast furnace slag, a waste material available in abundance at all the steel plants, provides lower melting temperatures up to 80°C and reduced fuel costs up to 10 -15 %. The known product of this type is Calumite.

Further reductions in soda are possible but a point may well be reached where the mettability of the glass can only be offset by incereased melting temperatures and consequently increased melting temperatures and consequently increased furnace fuel. Forming problems could also occur as they did in the earlier days of soda reductions but it may be possible to overcome these by improved forming techniques and the increasing use of automatic process control.

Perhaps the most important contribution which is now receiving attention is the elimination of raw material losses by routine material audits.

An example of new batch composition has announced for example Heye Glasfabrik from German Federal Republic. Since soda ash is the most expensive batch ingredient, appreciable savings have been realized by lowering Na_2O to 11,5 %, replacing Na_2O by cheaper CaO and MgO. Melting and working properties have been favorable, chemical durability is improved, thermal expansion lowered with resultant better thermal shock resistance and a better surface finish contributes to increased strength. No increase in energy for melting has been observed.

From indirect and total energy point of view the comparison of possible new and old glass and batch compositon is in Table 2. There can be seen that soda ash contributes 63 resp. 58 % of the raw materials energy.

But the most important source of energy conservation on side of raw material will result from usage of cullets, mainly in the glass container industry. 10 % more cullets is approx 2 to 3 % less of fuel.

In this context the big importance has the recycling of cullet. On all the world the industry has made considerable efforts to increase its use of cullet. It exists many of glass collecting schemes, but the most popular is "Bottle Bank Glass Recycling Scheme". A number of "Bottle Banks" - modified vandal - proof "skips", specially designed bulk containers which hold around three tonnes of waste glass , with colour coded compartements - are sited in convenient, busy locations normally visited by large numbers of people in their day - to-day or weekly business such as town centre car parks, civic ammenity sites, near supermarkets and other locations which are easily accessible to housewives and which would allow them to deposit a box or bagful of empty bottles and jars in the holes of "Bank" on regular shopping trips, by walk, bus or car. A publicity campaign promotes each "Bottle Bank" at local level and particularly remind housewives of the need to remove bottle tops and to separate the bottles into th-ree colours of flint /clear/, amber and green to ensure a supply of good quality cullet /recycled glass/ to the glass factories.

The local authority or special organisations or glass factory empties the Bottle Banks at regular intervals and except of glass factories organisation sells a bulk load of glass at a guaranteed price to the glass manufacturer. The glass is then cleaned, processed and remelted to make new bottles and jars.

The succes of this sheme documentate these figures:

In thousand tonnes of recycled glass

	1975	1980	1985
German Federal Republic	200	450	650
Great Britain		250	
France		290	600
Italy		310	
Switzerland	63		
Czechoslovakia	30	35	49
Owens Illinois - USA		110	

In German Federal Republic the production of container glass is approx 2,9 mil t/year, therefore recycled is approx 15 - 22 %, in Belgium 16 %, in Switzerland is was in year 1976 34 %. Between 4 and 15 kg of glass/year are normally today collected per inhabitant. Those 15 % in German Federal Republic means saving of energy equivalent to 90 000 tons of oil.

Systems for preparing cullets from external sources with capacities of 15 - 100 thousands tons per year can be described /Fig. 1/.

Glass which is ultimately intended to be recycled is fed either manually or mechanically into a hopper of adequate size /1./. It is then transported to an upward sloping conveyor belt /3/ by a vibrating feeder /2/ whose speed can be infinitely adjusted by the operators according to the amount of foreign matter present in the glass.

At the top of this inclined conveyor an electro magnetic separator /4/ is installed for picking out all the ferrous materials in the waste.

From this inclined conveyor the glass is carried to a sorting line /5/ equipped with flat belt where the glass is inspected by sorters. Pieces not of the dominant colour and large pieces of foreign matter are picked out manually,,thrown into chutes and collected in containers. Whole bottles and large pieces of glass are then crushed by a crusher /6/ to a size of 10 - 25 mm.

All material is fed to a swinging screen /9/ situated downstream the crusher. On this screen , a large part of the glass that of the chosen size and smaller, will be sieved off, so that only big glass pieces, the bottle caps of aluminium and plastic, the pieces of wood and paper will remain on the surface of the screen. As a consequence of their different specific weights the light foreign particles are then removed by a vacuum nozzle situated above the loaded conveyor, whilst the coarse pieces of cullet remain on the conveyor.

The glass cullet from the swinging screen /9/ and the vibratory feeder/11/ will then be charged onto a conveyor belt /12/. On top of this belt there is again a magnetic separator /13/ installed to remove iron particles.

The connveyor belt is then brought into the right position over the areas for accepting recycled glass.

In case the degree of contamination on the waste glass makes it necessary to wash the cullet, a washing drum can be installed before the swivel conveyor belt.

It is necessary to obtain this quality of cullets:

Nonglass contaminants %	Danemark	France	Switzerland	UK	USA	FRG
Organic /paper, plastics/	0,05	0,1	0,05	0,5	0,1	0,05
magnetic metal	0,005	0,1	0,1	0,1	0,05	0,0005
nonmagnetic metal /Al, Pb, Sn/	0,015	0,05	0,01	0,1	0,015	0,002
inorganic /rock, crockery, brick, refractories etc/	0,01	0,05	0,01	0,1	0,05	0,006

The price of cullet is approx 30 - 40 $/t for amber and green, 40 - 50 $/t for flint.

For the energy conservation then we can for normal container glass obtain:

Theoretical glass melting energy for batch	2 640 kJ/kg glass
Gases from batch heat loss	+ 176 kJ/kg glass
Totaly	2 816 kJ/kg glass
Theoretical cullet melting energy	- 1 865 kJ/kg glass
Energy saving for cullet melting	951 kJ/kg glass

Therefore the specific heat for melting with cullet is for normal regenerator furnace with firing efficiency 0,55

$$q = A - \frac{1}{0,55} \; /951.b/: 100 \quad \text{kJ/kg glass},$$

where „b" is cullet percentage, „A" specific heat consumption of glass tank.

Specific heat saving is

$$951\ /b_2 - b_1/ : 100 \text{ kJ/kg glass,}$$

where b_2, b_1 are percentage of cullet. For example for 10 % more cullet the specific energy saving is

$$\frac{1}{0{,}53 \text{ to } 0{,}65}\ 951 \,.\, 10 : 100 = 146 \text{ to } 180 \text{ kJ/kg}$$

/higher value for lower firing efficiency/

For modern glass tank with heat consumption 4 700 kJ/kg glass it is approx 3 % energy saving, for badly designed and operated tank with heat consumption 8 300 kJ/kg it is only 1,75 % energy saving.

The influence of cullet for energy conservation incl. raw materials energy and forming energy consumption is documented on Fig 2, where is percentage of cullet vs. heat consumption for netto sold glass for container glass. For cullet increase from 20 to 70 % we can see the fuel decrease to 78 %, that is for 10 % cullet the 4,4 % energy saving /incl raw material consumption/, with 1 kg cullet we can substitute approx 1,25 kg raw material.

Further energy saving with raw material can bring the agglomeration of glass batch combined with preheating and prereaction. Computations reported show that batch preheating to 700°C will reduce fuel consumption by at least 6 to 7 %. But beneficiation of this process is not clear and it is difficult to make specific statements as to total added cost of batch /approx $ 3 to $ 5 per ton/ vs. savings in terms of furnace size, refractory life, fuel savings, pollution control cost and quality of product. Several major test programs, pilot plants are under way, but the way to common use is still far.

Fuels

In the same way that raw materials require indirect energy before the product can be processed, so fuels require additional energy. Values have been assigned to all the fuels likely to be used by a glass container factory and these are shown in Table 3 in which the indirect energy is that required for the production of the fuel and its delivery to the consumer. The direct energy is that available to the consumer and is the gross calorific value of the fuel.

The production efficiencies of the various fuels have been calculated and the anomalous positions of coal and electricity can be seen. Electricity has an abysmal production efficiency of 24 % and therefore attracts considerable indirect energy. It is till this time a very expensive fuel in energy terms and its use in glass factories should be restricted to essential operations when made from oil or natural gas. Unfortunately, it is a very convenient energy source and requires monitoring in all its applications, particulary in its use as a boost fuel.

On the question of boosting, it is generally believed within the container industry that it can serve a useful purpose. Additional tonnage can be achieved to increase output from a furnace already loaded to capacity. The alternative is to increase the furnace size and suffer inefficiency at low throughputs. In either case there is a resultant loss in energy and the economics of the process also suffer.

In terms of heat transfer the use of electric boost is very efficient. Current practice suggests that 100 kW continuous energy input will produce 3,5 extra tonnes of glass per day, it is 2 469 MJ per tonne.

For normal top firing furnaces we require about 4 200 MJ per tonne.

In terms of total energies it is

for natural gas 4 200: 0,72 = 5 833 MJ/tonne
for heavy fuel oil 4 200: 0,84 = 5 000 MJ/tonne
for electricity 2 469: 0,24 = 10 287/MJ/tonne

Hence there is a considerable loss in energy when electricity is used to produce extra glass compared with that lost by the top firing fuels. There is considerable danger, therefore, in allowing the top fuel system to deteriorate and to suplement it by using electric boost, which should always be accounted for by the extra glass it produces when the top fuel system is operating at its maximum efficiency.

There is clear that this is valid for electricity made from fossil fuels. For electricity made from another sources the situation is quite another and from this point of view the electric melting can be the best solution for the future.

When we consider now for example container glass and suppose approx as it was said 13 GJ/tonne of shipped galss with relation electricity to fuel = 10 to 90 /see further/ than for average production efficiency for electricity 24 % and for fuel 75 % we can obtain the total energy for 1 tonne of glas in MJ :

	Factory usage	Total
energy of raw materials	-	4 439
electricity 13 000 . 0,1	1 300	5 417
fuel 13 000 . 0,9	11 700	15 600
Totals	13 000	25 456

Hence the ratio of total energy to factory energy to produce 1 tonne of glass is approx. 2:1, as it was said and look for the importance of indirect energy in glass production.

Glass plant energy distribution

As example I shall consider energy distribution for container plant, flat glass plant and energy distribution for Float line as example of modern large capacity line.

Container plant

Batch handling	0,25 - 4 %	average 2,0 %
Melting	60,0 - 80,0	70,0
Forehearth and forming	7,0 - 18,0	11,5
Annealing and inspection	2,0 - 8,0	6,0
Container handling	0,5 - 4,0	2,0
Space conditioning,services	3,0 - 15,0	8,5
		100 %

The average direct in-plant energy usage per tonne of glass is approx 10 to 18 GJ/t.

From further analysis we can derive that glass containers offer the potential of a substantial reduc of energy consumption - 20 % for the short term and fully 50 % over the longer term.

Ratio fuel to electricity for container plant /not all electric meltig/ is 93,5 to 75: : 6,5 to 25.

Flat glass plant

Bath handling	0,5 - 4,0%	average 2,0
Melting	70,0 - 85,0	75,0
Glass handling	5,0 - 15,0	11,5
Space conditioning, services	4,0 - 15,0	11,5
		100 %

Ratio fuel : electricity is 91 to 70 : 9 to 30 /not all electric melting/

Float line approx 640 t/day /MJ/hour/

	fuel	electricity	total	%
Melting	176 600	720	177 120	97,6
Floating	-	2 160	2 160	1,2
Annealing	-	2 160	2 160	1,2

Float line in Sankey diagram is in Fig 3

When considering possible energy savings the first to be considered is melting. The fault but is when only this energy is considered This is a mistake because savings can be made also in other areas of production, but the results are not so drmatic.

I wand now to examine some of the many ways, in which energy can be saved and I hope that it will stimulate your thinking on this subject.

Melting - control of melting cost

In connection with the melting proces one topic is always discussed: how to conserve energy? The melting furmace uses the largest amount of energy and it is logical to look for methods of conserving energy here, since this is also the stage of the process where the most energy is lost. The rising cost of energy and the growing urgency to conserve and utilize heat has put a responsibility on the glass industry to better understand its processes, mainly melting process, as the largest single use in the glass plant, and take steps to improve thermal efficiencies.

Where are we today in this field ? The best container furnace uses about 4 400 KJ/kg glass, the average energy consumption being between 5 900 - 6 700 kJ/kg, an electric furnace uses 3 140 kJ/kg. However, theoretically only about 2 500 kJ are needed to melt one kg of glass.

The days when a glass maker could sell every tonne of good quality glass that he could melt, without worrying too much about his melting cost, are gone. The spiralling costs of energy and the growing realisation that fossil fuels are not going to last for ever give good grounds for exercising close control over melting cost. The first step can be the setting up simple routines for monitoring energy consumption on a daily or weekly basis.

But first is necessary to say some words about representing of heat balance, because mainly on furnace heat balance are made very often some mistakes and bad concluseons.

The common method is the Sankey diagram. An example for cross fired regenerative furnace is in Fig. 4 and 5. The Sankey diagram represents heat or enthalpy flows in kJ/kg glass, kJ/hour or in %. From this diagram we can derive some very important coefficients for furnace operation comparison /see Fig. 5/:

$$\eta'_t = \frac{i_o + i_r - i_a}{i_o + i_r}$$ - for efficiency of energy transport in firing space

$$\eta_t = \frac{i_o + i_r - i_a}{i_o}$$ - the same efficiency incl regeneration

$$\eta_t = \frac{i_a}{i_o + i_F}$$ - the total efficiency

$$\eta_r = \frac{i_r}{i_a}$$ - the efficiency of regenerators

Sometimes is this diagram draught in cross section of the furnace /Fig 6/ or on furnace plane /Fig 7/ for better visual view.

One of the disadvantage of this method is the laboriousness. Trier and Werner have developed another sort of Sankey diagram, which is easier to draw./Fig. 8/. There are some rules for draughting:

1/ The parts of the equipment system are as squares on the diagonal
2/ Input heat from top, glass heat to the right, losses to the left, recovery heat from bottom.

Other rules are clear from the Fig. 8.
This method is easier to draw, but the principal disadvantage of Sankey diagram in every form remains.

It is that there is not enough clear what happens when is made some change in design or in operation of the furnace. The Sankey diagram is a good tool for comparison of two measurements,but not so perfect tool for energy saving development.

The Sankey diagram is only heat balance from the first law of thermodynamics point of view and not also from the second law of thermodynamics point of view and therefore sometimes some conclusions draught from this diagram can be false.

In fact every variable of the heat balance is made by the product of quantitative and qualitative variable $C \times \Delta \vartheta$ /J/°C, °C/ where $C \times \Delta \vartheta$ is heat flow, $\Delta \vartheta$ temperature diference. In the diagram $C - \vartheta$ which was developed by Černoch we can better follow all heat actions in the furnace.

I want to use this diagram only for demonstrating what happens when we need more or less heat for glass melting or for structural losses and how demonstrate the heat recovering influency.

In this diagram again the area is the heat flow or enthalpy flow. In Fig. 9 is heat balance without heat recovery. ϑ_k is the calorimetric temperature, ϑ_s is waste gases temperature from melting space. The total area is fuel energy delivered to the furnace. The utilized heat are areas of heat of batch melting reactions /1/, glass sensible heat /2/, structural losses under glass /3/ and over glass /4/. All these heat flows are calculated or determined in similar diagrams. We can now suppose better insulation of the furnace bottom. Then the structural losses /3/ will be less, but energy saving is not only the diminishing of these loses but the heat flow of the whole area as it is demonstrated in Fig 9. Similar it is in case of reaction heat diminishing /for example cullet using etc/.

In Fig 10 is as basis fuel energy with calorimetric tempecature ϑ_k as in previous figure. Now is demonstrated the heat recovery with combustion air prehe-ating in regenerators. The preheating temperature is ϑ_r and enthalpy of preheated air is done with $c_v \times \vartheta_r$, which is equal to change of waste gas enthalpy $c_{wg}(\vartheta_{sr} - \vartheta_{sp})$ where ϑ_{sr} is new waste gas temperature from melting space and ϑ_{sp} waste gas temperature from regenerators. This enthalpy change of combustion air is now added in area over calorimetric temperature /the rising of combustion temperature from ϑ_k to ϑ_{kr} /.representing the heat benefit from heat recovery. The area between new recuperative temperature ϑ_{kr} and new waste gas temperature ϑ_{sr} /which is now a little higher then ϑ_s / is now for utilized heat /1/ to /4/. Structural losses over glass must be a little higher, because the area temperature is higher.

We use only simple method, but in fact in diagram design we can consider structural losses of regenerator, cold air infiltration, dissotiation etc and so obtain more precise picture of the whole process.

Now back to some methods of monitoring fuel consumption and thermal efficiency of the furnace.

If the operation of any system or process is to be brought under control and directed along a predetermined path it is necessary to be able to see where the process stands currently, where it has been in the past and where it is heading towards in the future. One also requieres guidelines and data points relative to which a desirable course can be laid out.

The principle implies that accurate measurement of energy and of glass weight are essential, as are the keeping of past records and the delineation of a target line for future melting operations. An important conclusion is that adequate instrumentation of individual furnaces is essential for energy control.

Melting costs are controlled on the shop floor and the operators are provided with adequate instrumentation. The instrumentation has to be individual to each furmace and not simply one meter for the whole plant. Any economy is an aggregate of economies on individual furnaces and any wastage has to be traced to the individual furnace that is needing closer control.

A valid analysis can usually be performed on glass weight and fuel consumption data alone, which will account for most of the short term and long term variation of fuel consumption and will serve as a basis for a primary system of control. It helps in the interpretation of residual variation if historical records have been kept of events such as repairs and maintenance, alterations to burners etc.

Metering of fuels is obviously not difficult, weighing facilities that commonly exist for batch composition control are usually adequate for measuring the weight of glass melted.

The simplest form of fuel consumption model can be written as

$$y = a + bx$$

where y is fuel consumption, a is "no load" element of fuel consumption and bx is weight /pull/ x dependent element of fuel consumption.

This simplest model can be further developed with further factors as changes in cullet ratio in accordance with supply and demand, variation in batch moisture content, ageing factor which increases fuel consumption in time due ageing of tank /tank walls become eroded, burners deteriorate, regenerators get blocked etc/, linear or exponential - it can be 25 to 50 % between start and finish of a campaign - nonlinearity of weight dependent element due higher melting temperature with higher pull /which is perhaps necessary to the solution and homogenisation of the sand grains with shorter residence time of the batch in the furnace, factor for electric power of boosting input, outside temperature /summer, winter/ etc.

Necessary mathematical model of fuel consumption we can obtain by computation or by statistical analysis, or by both methods.

The simplest way is by macro furnace heat balance, it is with measuring of total energy input, glass melted and waste gas temperature and composition. Then the necessary fuel consumption equation we can obtain supposing that "no load" fuel consumption element in case of normal load is equal structure loss and one third of stack loss, pull dependent element is made by glass melting energy /weight time calculated or supposed total heat of a glass, based on its oxid composition - for example total heat to 1200°C for container glass approx 2123 kJ/kg, for flat glass approx 2 412 kJ/kg/ and "energy to fill" stack loss which is supposed with two thirds of stack loss.

Stack loss is determined from measured total fuel consumption, from which is waste gas amount calculated, from known specific heat of waste gas and from measured waste gas temperature. Oxygen content in waste gases can be used for combustion air excess determination.

An example of graphic determination from measured and calculated values of macro furnace heat balance is in Fig 11.

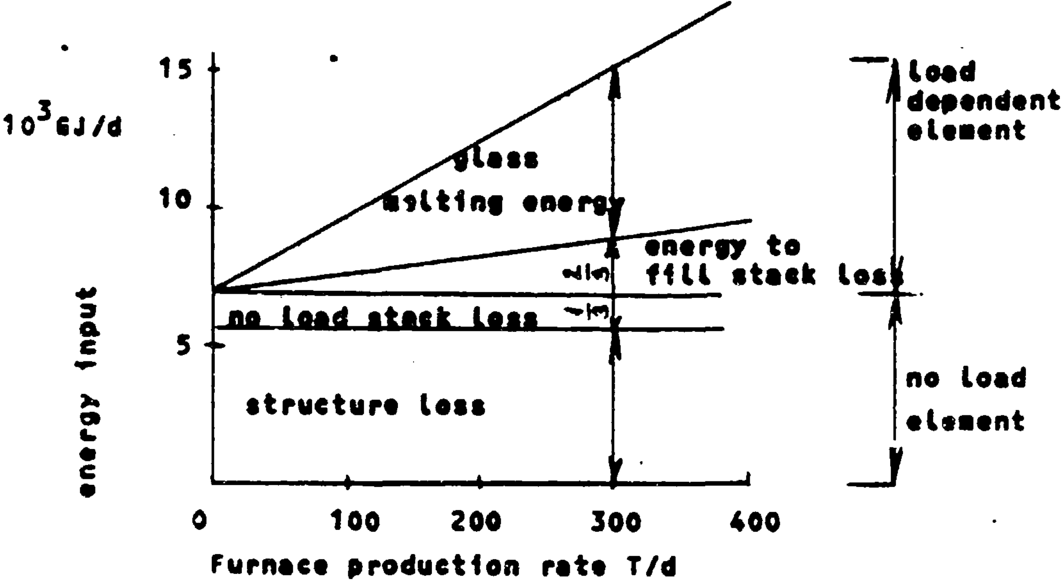


Fig. 11

Better and more precise method for specific furnace is statistical analysis. It can be based on week or day values of glass melted and fuel consumpted. The constat "b" can be calculated as average value of many "b" values, that were found from successive week or day values with significant pull change. Constant "a" is then calculated with known "b" value.

The monitoring of fuel consumption and plotting residual deviation of energy consumption from predicted values, usually on weekly basis, is a very good tool for energy control regime and analysis of furmace operation and behavior. The prediction model must, however, be reliable and thoroughly tested.

There is usefull to analyse not only currently obtained data, but also analysis of historical data comparison of two or nore furnaces can bring the answers for many important questions on energy conservation field.

Another tool for energy monitoring is heat balance. It is production people meaning, that it is rather laborious task and can be done only with special instrumentation and computation. However a simple, but accurate furnace heat balance can be made with data that already exist or are easily obtainable. For simple monitoring this may be all that is needed, but the macro balance can also become the base from which a more detailed furnace analysis is made.

From this point of view we can consider already mentioned macro furnace heat balance that consists from one total energy imput and three out-put variables - glass melting energy, stack head loss and structure loss.

The heating value of fossil fuels and electric power is known and consumption should be measured for each furnace. Stack heat loss calculation can be made from stack waste gas temperature measuremens, waste gas analysis and fuel amount knowledge. The energy required to convert raw materials to a glass can be calculated with known method and can be considered as constant for similar groups of glasses, because heat consumed in the chemical reactions is only approx 20 % of the total heat needed to raise the temperature of the melt to 1500°C. Total head for container glass is approx 2 600 kJ/kg, for flat glass 2 930 kJ/kg, for borosilicate 2 250 kJ/kg with specific heat approx 1,22 kJ/kg °C for container and flat, and little less for borosilicate. The knowledge of amount of melted glass is necessary. The remaining furnace structure loss is obtainable by difference.

Now on heat balance we can consider about energy saving.

The recent oil crisis with the resultant spiralling sky high costs of fuel oils have compelled the industry to seek new ways and means for the conservation of fuel in the melting of glass.

There are still some avenues where a lot of work can be done further to improve glass melting techniques, so that a better glass may be melted with still lower fuel consumption. Future programme may involve the following vital factors which influence the melting efficiency of a glass melting furnace and need serious consideration:

A/ Decrease of heat content in netto packed
  a/ lower weight of product unit
  b/ higher percent pack
  c/ higher cullet content
  d/ changes in glass composition and better choice of raw materials with lower melting temperature and lower total melting heat

B/ Increase of process system efficiency
  a/ process intensification
    1/ physical - chemical
      - batch agglomeration, preparation of glass batch and cullet
      - batch preheating
      - batch wetting
      - raw materials sizing

    2/ chemical
      - use of melting accelerators
      - use of refining accelerators
      - use of chemical activators

3/ thermal - improved heat transfer
- improved furnace design below and over the metal line
- use of proper fuel
- melting temperature increase
- combustion air preheating increase
- flame luminosity increase
- use of oxygen for combustion
- advanced burner systems with higher efficiency, ionization of combustion to provide more efficient heat release
- electric boosting
- bubbling

b/ reduce losses of heat and energy

1/ waste heat recovering with high-efficiency industrial heat recovery systems
2/ improved furnace insulation, shadowing, tighting
3/ reduce loss during firing reversation
4/ reduce combustion air exces and reduce cold air infiltration
5/ redume melting temperature
6/ reduce tank cooling on start of furnace campaign /with wall thickness over 100 mm/
7/ proper size of tank without "dead" space
8/ improved heat transfer in regeneratore
9/ optimalisation of furnace campaign time
10/ proper maintenance of the furnace, resp of regenerators, improved hot repairs
11/ higher performance refractory materials

C/ proper furnace operation and control

1/ computer controlled firing
2/ improved operating philosophy
3/ efficiency of temperature controlling devices
4/ production schedulling for optimum furnace load

There is not possible in this lecture to discuss about every possibility. Some of these look interesting on paper but the hardware and technology is yet to be developed. Some provisions can act in opposite direction /for example melting temperature - higher can intensify melting process but with increased structure heat losses, therefore exists optimum from heat consumption point of view/.

But some notes and some practical values can be usefull.

Cullet content - as it was said for 10 % more cullet approx 2 to 3 % energy saving

Batch agglomeration and preheat: can be more effective than heat recovery in regenerators - preheating for 700°C with waste gas can theoretically save in comparison with regeneration 6 to 30 % of fuel. Unfortunatelly the necessary hardware is not developed.

Particle size of raw materials, mainly of sand: the melting time is obviously determined by melting of sand, but not by average particle size, but by coarsest grains. For example in laboratory test melting time for grain size 0,8 mm is 165 min, for 0,6 mm 130 min, therefore melting time for 0,6 mm by 21 % less. We can suppose the increase of pull in the same size. We know, that for 10 % pull increase we need only approx 3 % of fuel more /this value is lower for advanced purnace, higher for bad designed furnace/, then for 20 % pull increase only 6 % of fuel more and so energy saving is approx 14 %.

As melting and refinig accelerators and chemical activators with resulting increased pull we can use fluorine, elementary sulfur, chlorine, lithium, boron, barium, slag, caustic soda and many others chemicals. Everytime we must consider the price, corosion and enviromental effect of these elements. The energy saving effect is in lower increase of fuel consumption in tank with higher pull.

Some considerations about fuels were already made in this lecture. It can be said that heat consumption for natural gas can be sometimes as much as 10 % higher than for oil. It is sonnected with flame luminosity.
In energy crysis were made tests with coal-oil mixtures, direckt glass melting with powdered coal as alternatives for industrial use, it was considered about better method of on-site coal gasification, but all these tests and ideas are still aware from common industrial use, technical difficulties are not yet solved.

It is known that higher melting temperature brings higher pull. Between 1 400 and 1 500°C for 10°C 5 to 10 % pull increase.

Combustion air preheat: for every 100 °C over 900 °C we can calculate approx with 5 % energy saving.

The contribution of oxygen use is higher for fuel with lower calorific salue, for bad designed furnace, for poorly insulated furnace. It is posible to calculate approx with energy saving approx 3 % for 1 to 2 % of oxygen. Energy saving is higher with higher oxygen amount.

Insulating: with proper insulation we can calculate with these values: /MJ/m^2 hour/

	without	with	energy saving
regenerator crown ports	50	9	41
side wall	43	5,4	37,6
bridge wall	40	8,3	31,7
bottom	19	5,4	13,6
crown	17	8,3	8,7

Proper insulation can bring energy saving 5 to 15 % with insulation initial costs equal approx 10 to 20 % from this saving.
Another interesting experience is that loss increase with furnace ageing is less with insulation.

Heat losses from openings in furnace wall result from radiation through the openings to the surrounding outside atmosphere and also from products of combustion escaping through such openings. We can calculate approx with loss.700 MJ/m^2 hour from radiation. Loss from stipg-out occurs when the internal pressure of a furnace is such that products of combustion are caused to be discharged from small or large unsealed openings in the furnace structure can be 5 GJ/m^2 hour.

Very important position in energy saving has heat recuperation or regeneration from waste gas. Regenerators and recuperators are used as a common method of heat recovery and hence improve the thermal efficiency of the glass melting process.

As air preheat increases potential economics from the extra heat available for melting is on the rise in theoretical flame temperature or on an assumed 55 % utilisation of heat returned to the furnace. A recuperator giving a 550 °C air preheat and a regenerator with a 1 000 °C preheat would allow 20 % and 35 - 38 % improvements in fuel saving at fixed load respectively, or would allow the same output increase.

The construction of regenerator chambers is a major contributor to furnace costs, and yet the design and size of the chamber is often the result of decision taken without proper consideration of the financial returns. Whilst the rigorous solution of regenerator thermal efficiency demands the application of highly complex mathematics, the use of simple approximations is of value to the glassmaker in developing guidelines to the selection and design which will give him the best return for the capital invested.

Further are some of approximations and simple empirical expression which can be applied to the problem of estimating the financial return expected by increasing the regenerator size.

As guidelines we can consider that regenerator efficiency is dependent on the area for heat transfer, gas velocity and will increase as the thermal conductivity, density and specific heat of the packing bricks increase.

Therefore we can write that heat returned as preheated combustion air Q is

$$Q = K \cdot v \cdot A,$$

where K is constant for one typ of regenerators / 1/, v is the air velocity and A packing area exposed in regenerator and available for heat transfer. All this values can be estimated on existing regenerators.

For higher preheat with the same refractories we can increase v or A or both. One of the ways can be enlarging of regenerators. Then we can compare the higher initial cost of regenerators plus higher cost of intermediate repairs and cost of higher heat returned as preheated combustion air in a furnace campaign and deside about the best solution.

According experience it appears that increasing regenerator height /even when free area remains constant/ is better than increasing free area at constant height from financial return point of view.

For enlarging of regenerators we can consider that the cost of packing is approx 15 % of furnace cost and for example in container industry it is approx 0,2 % of container cost. Energy cost is now climbing from 6 to approx 30 %, there-fore the right size of regenerators with energy saving will climbe, too. The common optimum size now is approx 4,5 m^3 to m^2 of melting area /factor of regenerators/.

This is derived from experiences with waste gas temperature /Fig 12/. For factor higher than 4,5 is temperature decreas in outlet only small and therefore no more significant energy saving to expect.

The benefits of air preheat push us to think about additional air preheating. This involves the use of a secondary regenerator or recuperator. The latest techniques of regenerator design and improved types of refractories have resulted in the appearence of secondary and tertiary regeneration even with additional initial cost and maintenance associated with them.Also reports have been made of a rotary regenerative air preheater. The desision depends upon the economics. As the cost of fuel increases and its availability decreases the incentive for additional preheat of the combustion air becomes greater.

As it was said approx. 65 % of the energy consumed in a glass plant is utilized in the melting operation and approx. 30 % of the energy consumed in the melting operation is again exhausted out the furnace stack /Fif. 13/, For the future the best way for utilization of this waste heat appears the batch preheating, but the technology is not yet solved. Technically is solved the use of boilers.

A waste heat boiler has the potential for recovering 50 % of the heat exhausted in a furnace stack by temperature dropping from 450 to 200°C. Thus a glass plant could reduce its total energy consumption by as much as 10 % if waste heat boilers were installed on all furnaces. Obviously the plant must have a use for the steam or hot water generated by the waste heat boilers to make this economically viable.

The use of boilers can be for

- space heating and hot water preparation
- steam production for machine drive /fans, blowers, pumps/
- steam production for electric power generation eventually combined with heating /Fig 14/.

For heating we must consider that heat consumption during the year is in ratio approx 1 : 10 /July-January/ and therefore utilization time is dependend on power installed. With higher power installed and higher grade of waste gas energy utilization is higher initial capital cost and lower utilization time.

A calculating taking capital costs into account shows that use of waste heat only for factory heating is the most economical short term method of using waste heat in a glass plant. However, taking into account the technical and economic working life of the installation, use of the waste heat for electricity generation could give greater total savings.

Another benefit o. boiler is that the temperature of the waste gases behind this system is only approx 200°C and it is thus easily possible to clean them so that they become even less dangerous to the environment.

Prior to the installation and operation of a waste heat boiler on a glass melting furnace a preliminary survey must be made:

- furnace melting load history and fuel requirements to determine operation conditions in time and thus to determine exhaust folume and boiler size
- furnace exhaust characteristics - temperature and oxygen content. Oxygen content for calculation of exhaust volume from fuel usage and also for indicating of any major leaks existed in present dusting
- existing steam and/or hot water system conditions, the level of year-round steam and hot water demand
- available space near the tank
- governmental boiler code for requirements for design and operation conditions of steam boilers.

They exists two key boiler design variables - the velocity through a waste heat boiler and the boiler's outlet gas temperature.

High velocity through the boiler assures high heat transfer and reduces fouling. Since a waste heat boiler depends entirely upon convectiv heat transfer,,the velocity in a waste heat boiler must be higher then in fired boilers. On the other hand, as the velocity is increased the pressure drop through the boiler increases and a tradeoff must be made.

The outlet temperature should be set high enough to avoid condensation of the waste gas stream and prevent corrosion. The steam or water condition and type of melter fuel will alse influence the choice of outlet temperature. Once the steam or water condition is known and the outlet gas temperature and the velocity chosen, the boiler can be specified. Ideally, a waste heat boiler will be designed to recover the desired amount of heat while minimizing the boiler size and pressure loss through the boiler.

It can be used firetube or watertube boiler. Firetube boiler can be less expensive for low steam pressure and steam ammount. Sometime for electricity generation the steam can be superheated in another boiler fired by oil or gas.

Some requirements that must be considered for waste heat boiler installation:

- breaching and return of gas stream: breaching should be made near the reversing valve. It can be considered returning to the existing stack or to built an additional stack, usually with own blower to overcome the draft loss through the boiler.
- to minimize pressure drop, air infiltration and heat loss: placing of boiler as near as possible to the breaching. The duct work should be insulated to reduce heat loss and gasketed by flanged connection to prevent air infiltration.

- provision for tube replacement:and cleaning: enough acces to the boiler to be able to service the boiler for inspection, cleaning and maintenance, incl the tube bundle replacing eventually. Provision for cleaning is of most importance /rodding, steam cleaning, adding of magnesium oxide powder upstream for avoiding the low melting eutectic and obtaining a dry, friable deposits/
- weather protection when outside installation /instruments, electric equipment, but also boiler in severe winter/.

In boiler in Fig the exhaust gas flows from below the ground flue into the furnace exhaust plenum. In the plenum, provision has been made for the exhaust to take an alternate route through the waste heat boiler. When the boiler is not in operation, the boiler cutoff valve is closed and the melter stack valvu is open. The furnace is exhausted as it normally would be.

When the boiler is in operation, the boiler cutoff valve is open and the melter stack valve is closed, directing the gas flow through the boiler and up the boiler stack. As the hot flue gases flow through the boiler, heat is absorbed by the water in the shell, and steam is produced The boiler stack control valve is a damper used to control the suction of the boiler exhaust fan so that the draft on the furnace is the same regardless of direction.

The key to a successful waste heat boiler operation is to design the waste heat boiler as a slave to the furnace. Furnace operation must be given first priority. For this reason is very important a proper control scheme. Draft and flow conditions on the furnace mustn't be influenced especially at later stages of the furnace campaign. A proper draft control system is necessary to compensate for any change in draft to the waste heat boiler through dust and dirt collecting from the exhaust gas for example.

Automatically boiler system shut down and/or activating alarm system when boiler sontrol cannot maintain a set point for draft on the furmace, is necessary. In proper conditions and by proper design a utilization time of 90 % can be achieved incl. downtime for cleaning,, that can be every two, three weeks.

Another possibly system for heat recovery from waste gas is a gas turbine for electric power for compressed air supply. A working system requires either energy extraction via a heat exchanger under positive pressure or direct passage of waste gases through a system that is preferably subatmosferic. The waste gases must be clean, free from particulates. This system is under testing in USA in laboratory conditions and not in industrial use.

For future it can cowe another melting systems, too. For example researches at Battele has developed "particle veil process" which could have the effect of reducing energy consumption by over 30 %. In this process no more the batch is fed onto the surgace of the glass bath, thus forming a thermally insulating layer between the burners and the bath surface, poor heat transfer results between the source of heat, the charge and the molten glass bath. The new process improves the heat transfer from the heat source and the bath surface to the charge by using pelletized batch material and injecting the pellets directly into the flame of a flat flame burner, thus forming a veil of particles. An important condition is that the process parameters are so selected that the pellets melt while in flight and join the bath surface as droplets.

It is inly one example for demonstrating that todays technology of glass meltig is not the last step and thet together with heating development will further develop the whole glass melting technology.

Glass melting energy must be the first to be considered in energy consuption within the glass factory, but not only considered factor.

Let us examine also another energy consumption in whole chain of glass production.

Saving energy not only during the melting process but also during forming is another programm. About 20 to 25 % of total energy consumed in a glass plant is used in the forming machine area.

The forehearth - feeder uses 5 % of the total fuel consumed in the tipical glass container manufacturing plant. Ways in which forehearth energy conservation have been achieved include better temperature control, use of electric heating, and improved forehearth maintenance.

In forming area, where electricity is the major energy source, savings have been realized trough improved cooling air efficiency, closing off the cooling wind when the mold is open, electronic timing, better control of cooling air fans, use of energy-efficient motors, better production scheduling and lightweighting.

Very important equipment in glass factories are cooling fans, blowers and pumps. This equipment uses approx 40 % of all electricity used.

The advanced design of molds cooling can for example bring saving in container production. Theoretically only 10 % of the installed cooling air is actually necessary to cool the glass during forming and all the rest is energy lost.

Almost all cooling equipment is driven by constant-speed ac motors and for flow control throttling valves are used. But this control method can waste up to 30 % of total electric power. Adjustable speed operation of this equipment is solution of energy savings.

For explanation we can consider the typical fan or pump operational curve /Fig 16/,where is plotted pressure vers-us flow. The curve shows that the fan will produce limited flos with higher pressure and higher flow with reduced pressure. How the equipment will operate in a given application is done by a system curve which has static head part and friction head part, increases with increasing flow. Friction head is the resistance to flow provided by the pipe valves elbows and other system elements. The intersection of equipment and system curves shows the natural operating for the system without flow control.

If a control valve is added, and partially closed to throttle flow, it increases the friction head. The modified system curve and new operating point are shown as throttled system curve in Fig 16. Although the desired flow was achieved the head has been increased.

If flow control is done by modifying equipment speed, flow and head are reduced together. This greatly reduces equipment horsepower, because pcwer is proportional to head times flow. In Fig L7 the horsepower needed for each method is shown with rectangles superimposed on th-e equipment and system curves. The reduction in horsepower needed with adjustable speed control /B/ is dramatic when comopared to the valve control method /A/.

The advanced solution of adjustable speed control for ac motors is solid state motor drive. Energy saving is in Fig 18. Most solid-state adjustable speed controllers for standard ac induction motors vary both the voltage and frequency. Frequency is controlled to vary motor speed. Voltage is varied /along with the frequency/ so that torque can be controlled. A constrant relationship between voltage and frequency is maintained.

To control voltage and frequency, a controller must alter the standard ac utility power. This is done by first rectifying the constant frequency input voltage into dc voltage, then inverting the dc into variable voltage/variable frequency ac power. This type of power conversion device, and the ac motor to which it is applied, are together called a variable frequency drive /VFD/.

The three basic VFD methods used in motors of less than 500 hp are variable voltage input /VVI/, current source inverter /CSI/ and pulse width modulated /PWM/ drives /see Fig.19/.

The VVI drive uses a controlled rectifier to transform ac voltage to dc voltage. By sequentially switching transistors or thyristors in the inverter section in six discrete steps, the VVI drive produces a variable frequency output. The VVI controller has the simplest regulation scheme, but it uses the largest number of dc filter components.

A CSI drive also uses a controlled recfifier to convert ac to dc, and its inverter section produces variable frequency six-step output current. The main advantage of a CSI drive is its ability to have complete control of motor current. This results in complete torque control. However, this current- controlling ability needs a large filter inductor and a semi-complex regulator.

The PWM drive uses a diode rectifier to provide a constant dc voltage, The inverter section controls both voltage and frequency. This is done by varying the Width of the output pulses, as well as the frequency, so that the effective voltage is almost sinusoidal.Because a PWM controller outputs near sine-wave power to the motor, less power filtering is needed. But, complex switching waveforms in the inverter require a complex regulator and switching losses can be high.

The following generelszitions on VFD efficiencies can be made:

1/ At full speed and full load, where drive efficiency is most critical, the three types of VFD's are close in efficiency - typically 85 - 90 % including both the controller and motor.

2/

2/ efficiencies of all three drives vary depending on horsepower rating and operating conditions. Higher hotsepower drives tend to have higher efficiencies.

3/ motor losses are a function of load current /which is the same regardless of drive type/ and harmonics. As shown in table PWM drives are the best choice if harmonics create a problem.

4/ The CSI controller tends to maintain better efficiency than the others as operating speed is reduced.

5/ The PWM drive has a power factor close to 1,0 due to its diode rectifier input and constant potential dc bus. The power factor of VVI and CSI drives declines with decreasing speed because of variations in firing angles for the thyristors.

Comparing drive methods: / 1 = best/

	VVI	CSI	PWM
Drive cost	1	1	3
Drive /motor and control/ efficiency	3	1	3
Power factor	3	3	1
Maintenance	1	2	3
Reliability	1	1	3
Complexity			
Power circuit	2	1	3
Regulator	1	2	3
Harmonics	3	2	1

The VVI and PWM drives are relatively simple to apply. As long as the controller is large enough for the load currents, it's fairly easy to apply these drives to centrifugal loads. The motor won't overheat at low speeds because of the big reduction in motor current.

With a CSI drive, the ac motor is a vital part of the system. An improper motor selection can cause unstable operation. This risk is reduced by purchasing the motor and controller from ome source. Properly applied, the CSI unit offers several features that enhance its reliability. First, special "inverter grade" fast turn-off thyristors aren't needed, so replacements are easier to buy and cost less. Second the drive controls current rather than voltage. This means that it has high immunity to load side transients and short circuits. Third, the power circuit design is not complex and can be understood by repair personnel familiar with electrocal devices.

Servicing any VFD is hard for those unfamiliar with motor drives. Many manufacturers are seeking ways to solve this problem by providing simple diagnostic equipment as an integral part of the drive.

The state-of-the-art has progressed greatly in electronics over the last ten years. Advances in solid state have produced large scale integrated circuits which will continue to improve electric drives. Motor drives should continue decreasing in codt and increasing in performance in the years to come.

Huge increases in energy costs have made adjustable-speed flow control with solid-state drives economical.

Another problem with air is leaking compressed air lines.We can consider that approx. 40 % of electricity bill in container plant is for compressing air. Some measurements on machines indicated that 20 % of the compressed air was being lost through air leakage. If we are conservative and claim only 10 % less through leakage, then approx. 4 % of the electricity bill is wasted . Therefore careful attention must be paid to the compressed air piping so that leakage is kept to minimum, quality of connectors must be improved. If heating gas were piped in the same way as compressed air we should be in constant trouble.

But not only for compressed air. With fan air the situation is similar and need our attention, too, even with no so dramatic saving results.

Annealing lehrs

Annealing and decorating lehrs in the typical glass container manufacturing plant utilizes approx 8 % of the total energy, now mainly electric energy. Fuel saving in annealing area has benefited from use of recirculation systems for more rapid heat transfer, internal belt returns, improved insulation and use of electric heated units.

Practically it means these provisions:

1/ The highest possible temperature of products on input of the lehr

2/ Advanced design of the lehr, especially

a/ use of radiant roof as first section of the lehr. Radiant heating with proper tuning of the energy ~~ami~~ emission source to the absorption characteristic of the product is the most rapid method for heating in this part of the lehr.

b/ recirculating system that provides a high rate of air recirculation which gives excellent sonditions for rapid heat transfer at low temperature differentials. The individual recirculating sections provide a unique system for an effective barrier to forward drift, particularly along the sidewalls where this problem traditionally causes loss of annealing quality. The rapid heat transfer and the prevention of tunnel drift are important energy saving factors. Another possibility is in installing air curtains on annealings lehrs The lehr curtain could result in a 10 % energy saving.

c/ internal belt return through the tunnel and so not to cool the belt to ambient temperature

d/ advanced insue-lation of the tunnel with advanced materials. Surface temperature should not be higher than 40°C on every place and at all time

e/ with gas heating the high velocity burners can achieve recirculation in a lehr tunnel without the use of recirculating fans and so to save motor energy for these fanns. On gas heated lehrs other potential areas of energy savings is preheating, insulation and combustion air recovery.

Result of these improvements can give the total heat consumption on lehr approx 20 kW.

Tempering

Similar to the lehrs is the problem of tempering furnaces. Measurements provided on these furnaces demonstrate high loss with not enough tightness of the furnace, especially in vertical provision. Apprix. 50 % of input energy is lost, while heated glass takes 25 % and the rest is furnace surface loss. Improvements on furnace design can bring substantial energy savings.

Another energy saving resources

Among the new technology being applied also in glass plants is for example radiative burners, heat pump systems, solar energy utilization, expansion of high pressure natural gas in turbine with electric power generation instead of common pressure reduction, electronic control gear for fluorescent lamps, automatic control of space lighting etc.

Electronic control for fluorescent lamps reduce power losses from 25 % to approx 10 % of the lamp power, use of solar energy has been reported for water preheating for glass factory boiler and substantial energy saving was achieved.

Interesting is the use of the heat pump systems for recovering low grade heat, for low potential waste heat utilization. But while heat pumps use less fuel than boilers, they cost more and cannot achieve very high temperatures.

Energy management and energy efficiency programs

In order to come to a final conclusions about energy saving, it is necessary to say something about the management of energy, as this is the only way to make energy savings happen.

On energy conservations works energy board with some members. The board represents all of the various specialties in the glass works that have some relationship to energy conservation.If you look at all of the various engineering departments, you will note that each has some component involved with energy.

There is recommended to establish Company Energy Policy Commitee. It should have overall responsibility for company energy management program. The commitee chairman is a company vice-president. The commitee is comprised of vice-presidents from all key areas of the company which involve energy. Each of operating divisions has an energy coordinator and divisional energy commitee. At the operating level, each divisional facility also has an energy conservation coordinator. The coordinators have responsibility for carrying out energy conservation program. The divisional coordinators are responsible for establishing conservation goals and reporting progress towards those goals for review by the Company Energy Commitee on a quarterly basis.

Each operating division define a unit /or units/ of measurement /energy per units of production/. It is established the base year performance. The percent improvement in energy utilization for each reporting organisation is then reported quarterly versus quarterly determined goal and the base year. The improvement of the whole company can be obtained by multiplying of each organization's percent improvement versus their base year by fraction of total company purchased energy in base year used by the respective reporting organization. These figures are then summed to obtain a company performance. These summary reports are made quarterly on a 12 month moving average basis and so is eliminated the seasonality of energy consumption.

My company has for example flat glass, containers, technical glass, lighting glass and fiber glass divisions. In base year 1978 they had 41, 26, 15, 12,resp 6 % of total company purchased energy. The improvements in % versus base year were according next table.

	Flat	containers	technical	Lighting	fiber
2/IV 1981	8,24	11,82	7,66	6,59	7,38
1/IV 1981	7,50	11,02	7,06	6,01	6,80
4/IV 1980	6,92	10,54	6,24	5,55	6,28
3/IV 1980	6,44	9,82	5,66	4,98	5,68
2/IV 1980	5,92	9,20	5,02	4,42	5,22
Ø 2/IV/80 - 1/IV/81	6,70	10,145	5,995	5,24	5,995
Ø 3/IV/80 - 2/IV/81	7,28	10,80	6,655	5,782	6,535

The company improvements 1/IV 1981:

6,70 . 0,41 + 10,145 . 0,26 + 5,995 . 0,15 + 5,24 . 0,12 +
+ 5,995 . 0,06 = 7,27 %

The company improvements 2/IV/1981 :

7,28 . 0,41 + 10,80 . 0,26 + 6,655 . 0,15 + 5,782 . 0,12 +
+ 6,635 . 0,06 = 7,87 %

In fact we use more units, minimum for melting energy consumption more, melting therefore that it forms approx 60 to 80 % of whole energy consumption.

The setting of goals and establishing of monitoring criteria is an important part of achieving evergy conservation, whether it be on a company, a divisional or an individual plant basis. The process of setting requires top management commitment and involvement. For divisions it is made in Company Energy Policy Commitee, for plants in divisional energy committee after setting in Company Committee and according the real situation and opportunities of each plant.

The activity on energy conservation can be divided into three areas of responsibility and activity:

1/ Plant practice or operating discipline, which is under the responsibility of plant management and spervision. It is important that all employees be aware tha energy is scarce and very expensive. Any place that they see waste taking place, they should take steps to reduce it or to call it to management's attention.

2/ The technical consultation on performance of existing process equipment - checklist for plant energy consumption inventory for searching of energy conservation, consulting manuals, seminars on various aspects of a plant's operation, training programs.
Very useful in the area of technical assistance is survey on energy consumption or total energy audit of plant, made by company engineering staff or by external experts. Energy audits provide a base line for judging future changes in the same plant, a basis for comparing performances of different plants, a basis for process R + D priorities. The first complex audit in the plant is not cheap and take min 1 month and for pursuing are necessary many special instruments. But benefits are big.
Very useful instrumentation is the thermovision system. It is a TV-like scanning system designed to detect heat loos or heat gain. These are recorded on thermograms which show where energy is lost and how serious the problem is. This simple technique displays actual energy losses and identifies areas where the most cost-effective improvements can be made.

3/ New process development, that is replasing existing equipment with more energy-efficient ones and existing process developments /new control strategy, better and more sofisticated instrumentation and automatic control, heat recovery, simply process improvements from energy point of view/.

The basic rules for energy conservation programme are:

1/ Make an Energy Survey and identify conservation opportunities
2/ Analyse the energy saving opportunities
3/ Evaluate the opportunities and make recommendations
4/ Plan the action
5/ Organize the management of the action programme
6/ Monitor the results
7/ Keep everyone informed of the results and help to maintain their interest.

Every once in a while it is helpful for the chief executive of an operation or business to conduct a senior management brain-storming session on resource utilisation in its broadest sense which will, of course,, include energy either directly in its own sight or indirectly via bought out supplies or the other main resources of space, plant, processes and people all of which have energy ramifications. It has, for example, been assessed that the energy content of bought out supplies used in a business can be up to four times the direct energy used by the business. Almost any activity thas an energy related aspect and in all these examples energy content can be one of the criterie considered in reviewing and decision making.

An added advantage of this approach is that it generates a greater personal involvement of senior functional management in the corporate dialogue and at the same time encourages a more objective view to be taken of their own specialised activities. It is experience that it is every bit as important to get functional management actively participating as it is to have the support of the chief executive.

Another helpful move is to get resource utilisation in general, embracing energy conservation, included as a regular item on the agenda of management committee and board meetings. In all this activity one thing has to be borne in mind we are trying to reduce the amount of energy we use per unit of output in terms of output per unit of added value. All our energy saving activity should ve related to output, otherwise we will be misleading ourselves over the effectiveness of our actions.

We have to learn to use energy more effectively.

And this was the purpose of this lecture, too.

Table 1

Energy required to produce raw materials /MJ/tonne/

material	indirect	direct	total
Sand	240 - 920	200 - 600	430 - 1520
Limestone	202	326	528
Soda ash	1 669	11 602	13 271
Cullet	43	230	273
Felspar	1 392	1 164	2 556
Alumina	7 902	26 818	34 720
Calumite	581	908	1 499
Sodium nitrate	101	51	152
Sodium sulphate	1 448	3 260	4 708
Calcium sulphate	577	194	771
Selenium	36 742	43 745	80 487
Cobalt, nickel oxide	1 649	3 949	5 598

Table 2

Energy balance of hypothetical new and old glass composition for the production of 1 tonne of glass /in MJ/

Chemical composition:

	old	new
SiO_2	71,9 %	73,2 %
Al_2O_3	1,5	1,5
$CaO + MgO$	11,8	13,5
Na_2O	14,5	11,5
SO_3	0,3	0,3
	100,0 %	100,0 %

Batch composition - old /new/

Raw material	weight/kg/	indirect energy	direct energy	total
Sand	655 /669/	386 /394/	312 /319/	698 /713/
Felspar	87 / 87/	122 /122/	102 /102/	224 /224/
Limestone + dolomite	222 /247/	45 / 50/	72 / 81/	117 /131/
Soda ash	225 /175/	375 /292/	2606 /2027/	2981 /2319/
Sulphate	25 /23/	37 /33/	82 /74/	119 /107/
Totals	1214 /1201/	965 /891/	3174 /2603/	4139 /3494/

The delivery energy is approx 200 to 300 MJ

Total energy old 4 439 MJ/t

new 3 794 MJ/t

Table 3

Energy associated with fuels

Fuel	Unit	Indirect energy	Direct energy	Total energy	Production efficiency %
Heavy fuel oil	MJ/l	7,81	41,11	48,92	84
Medium fuel oil	MJ/l	7,73	40,49	48,22	84
Light fuel oil	MJ/l	7,61	40,38	47,99	84
Gas oil	MJ/l	6,78	37,68	44,46	84
Diesel fuel	MJ/l	6,82	37,71	44,53	84
Petrol	MJ/l	5,53	35,97	41,50	87
Propane	MJ/kg	16,20	50,00	66,20	75
Butane	MJ/kg	16,20	49,30	65,50	75
Town gas	MJ/MJ	0,39	1	1,39	72
Natural gas	MJ/MJ	0,39	1	1,39	72
Coal	MJ/kg	1,50	29,30	30,01	97
Electricity	MJ/kWh	11,48	3,60	15,08	24

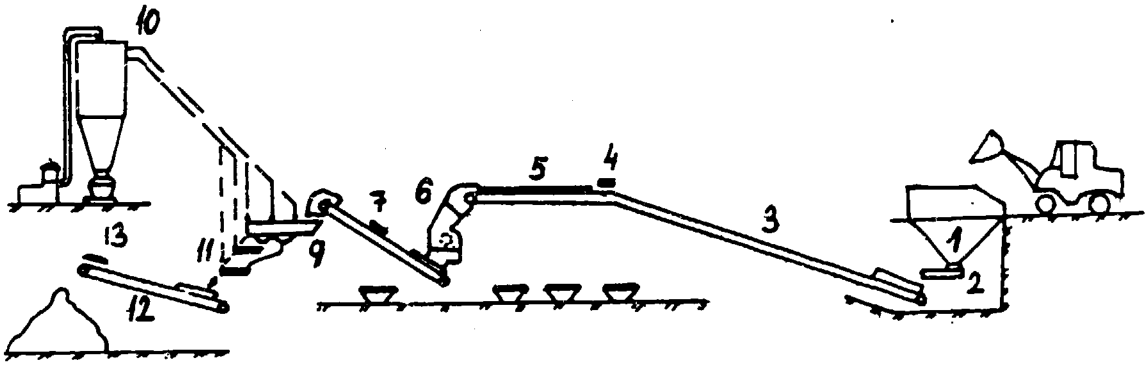


Fig. 1

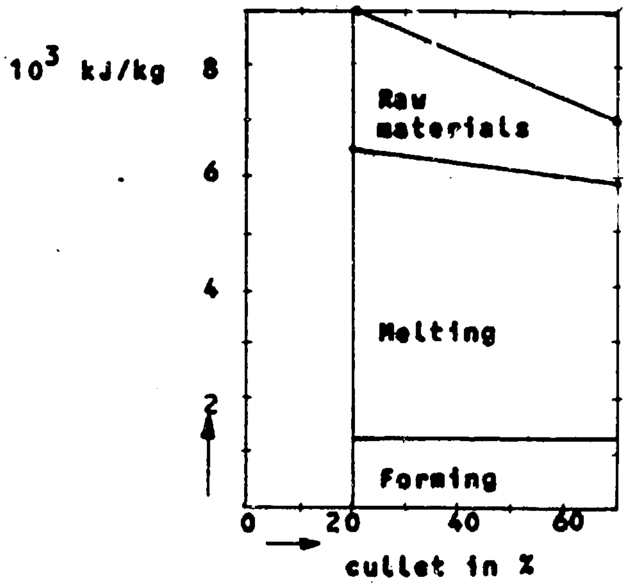


Fig. 2 Energy consumption in container glass dependent on cullet percentage

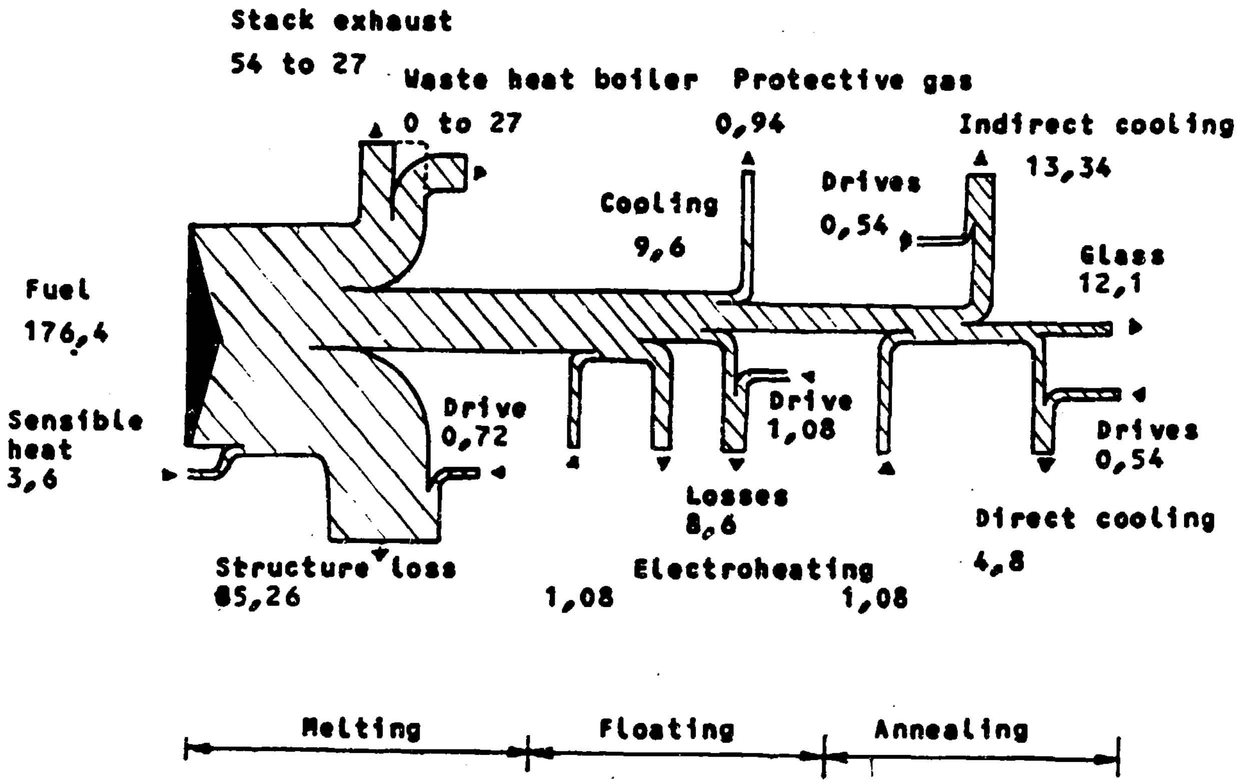
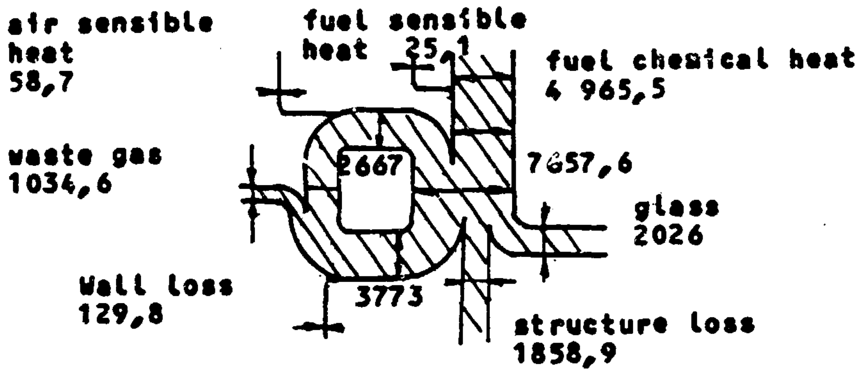


Fig. 3 Energy balance of Float line /GJ/hour/



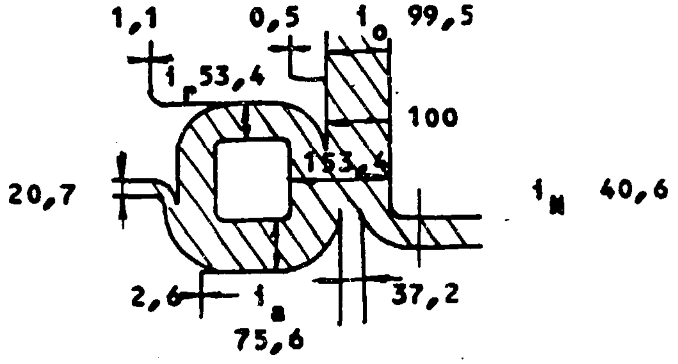
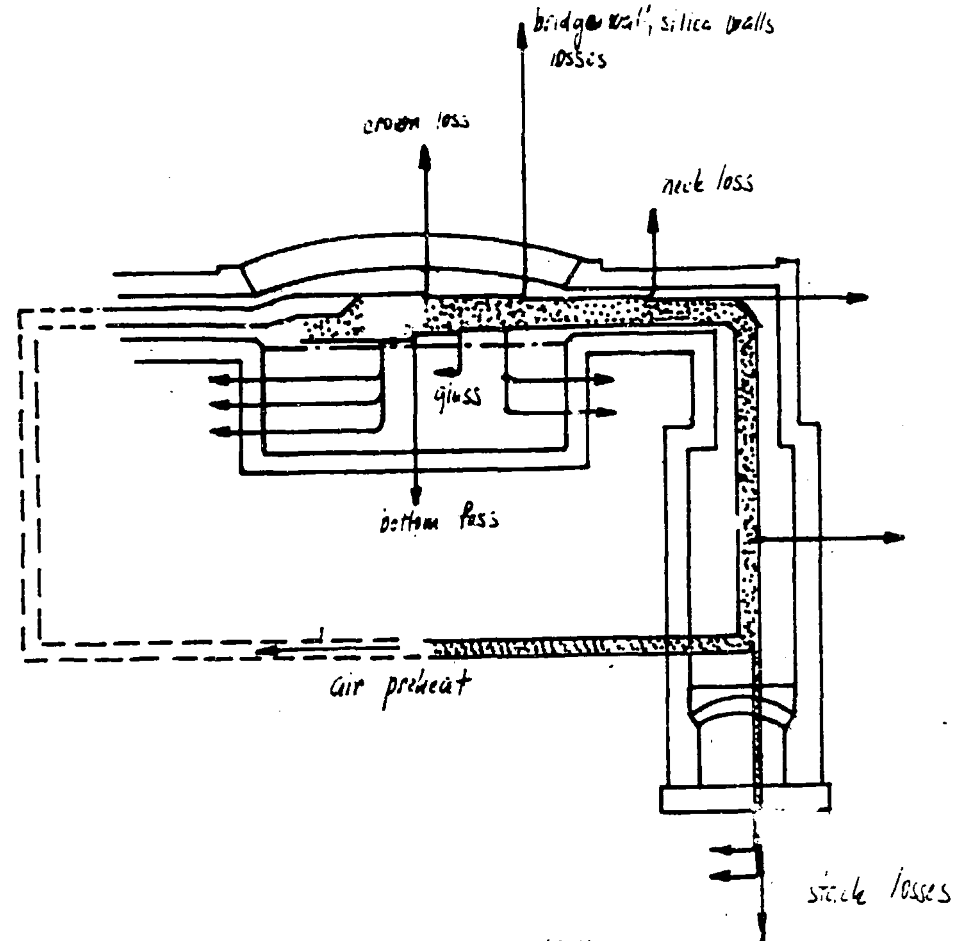


Fig. 4 Heat distribution in cross fired regenerative furnace / kJ/kg glass /

Fig. 5 Heat distribution in cross fired regenerative furnace /%/



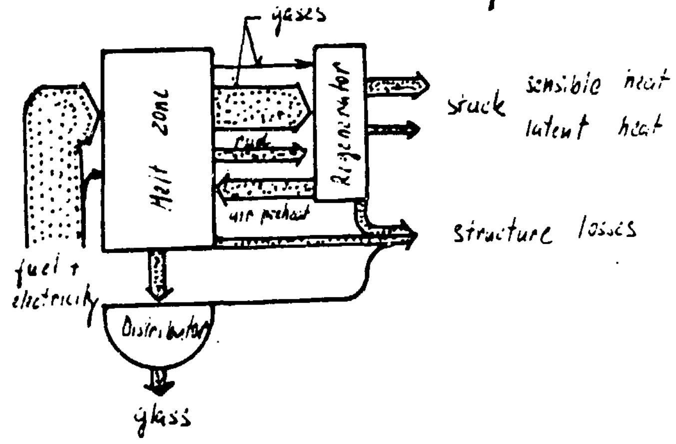


Fig. 6 Heat distribution in cross section of regenerative furnace

Fig. 7 Heat distribution in plan view of regenerative furnace

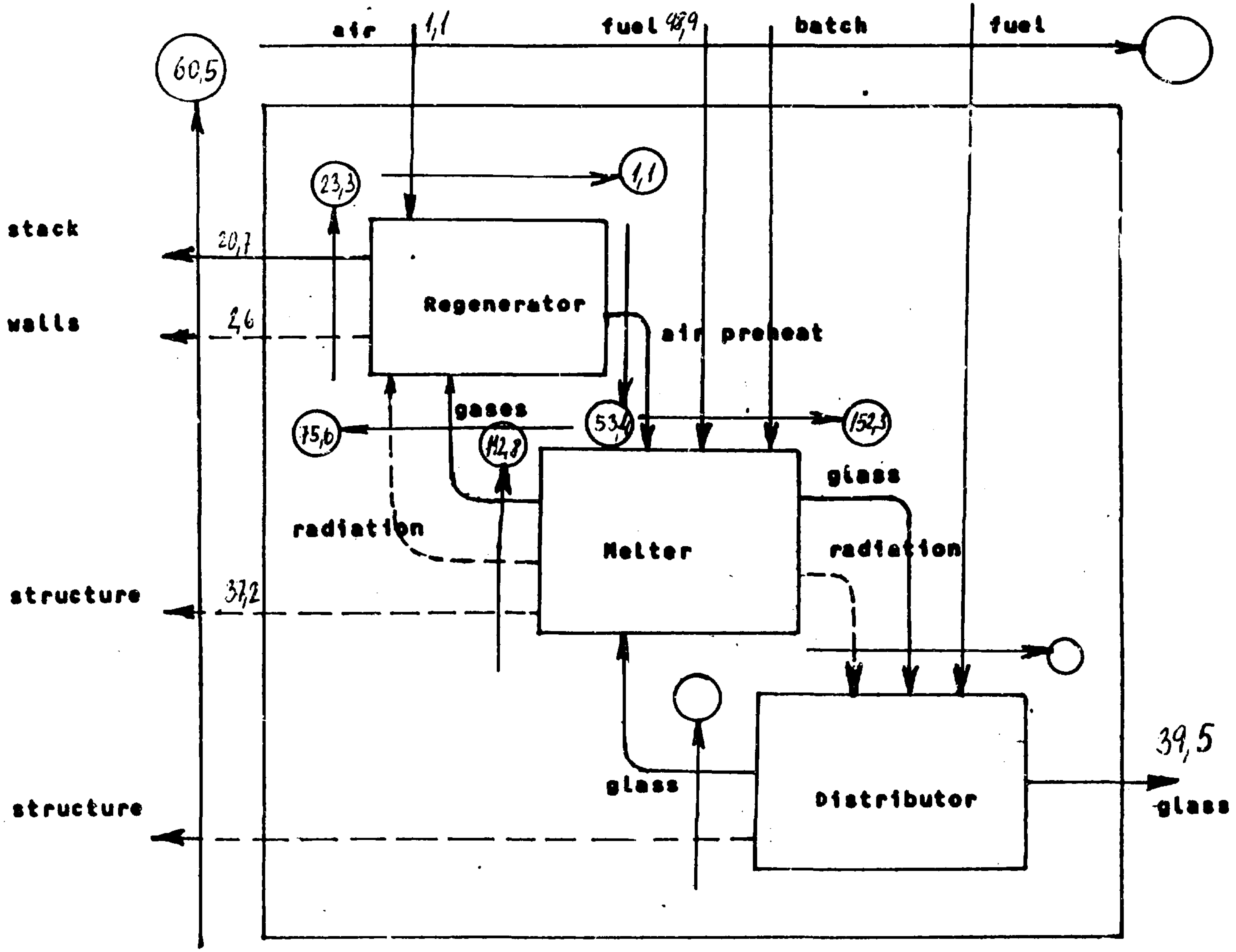

air
1,1
fuel
48,9
batch
fuel
60,5
23,3
1,1
stack
20,7
walls
2,6
Regenerator
air preheat
gases
75,6
142,8
53,4
152,3
glass
radiation
Melter
radiation
structure
37,2
glass
Distributor
39,5
glass
structure

Fig. 8

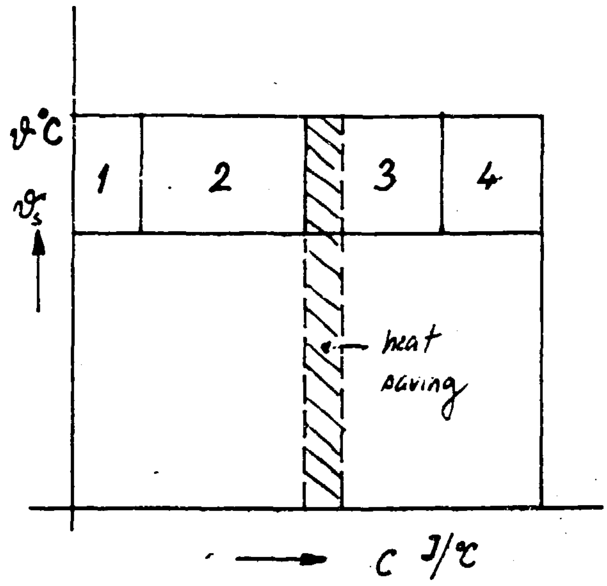


Fig. 9

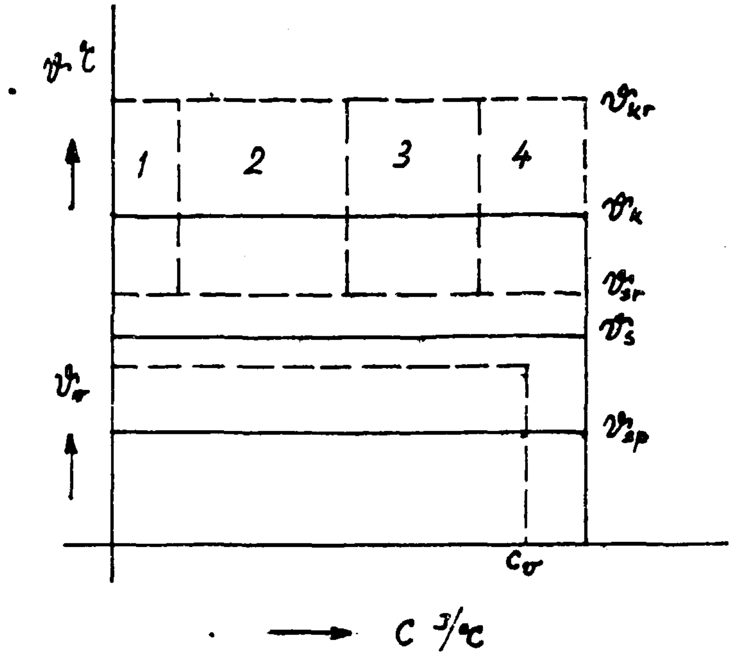


Fig. 10

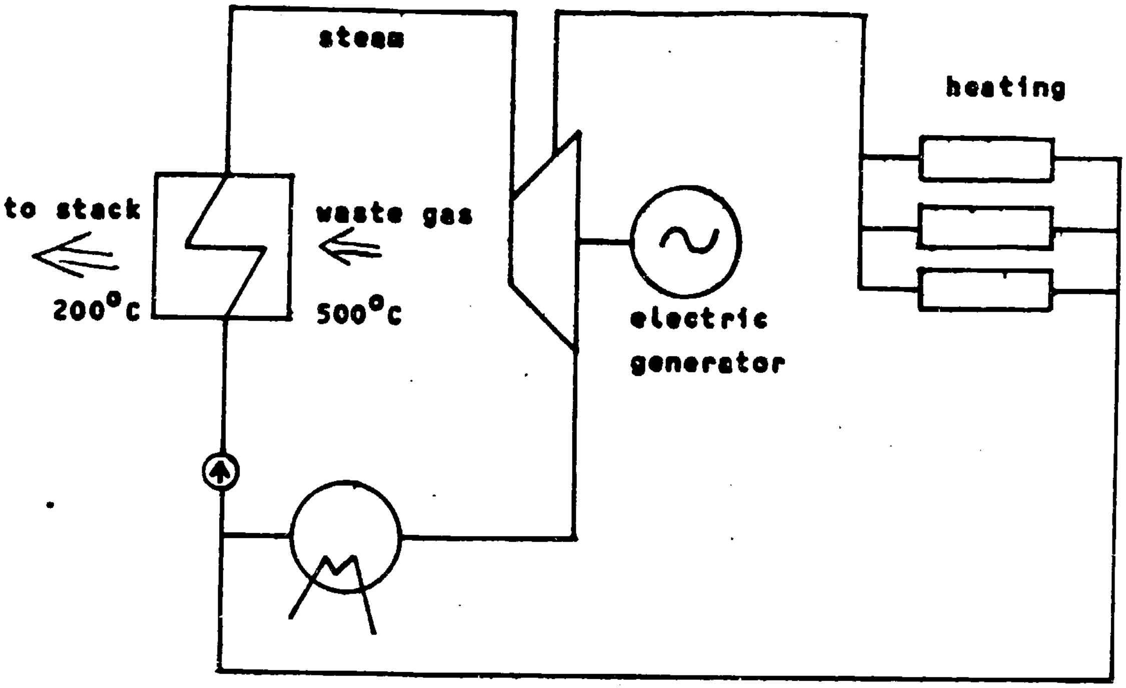

steam
heating
to stack
waste gas
200°C
500°C
electric
generator

Fig. 14

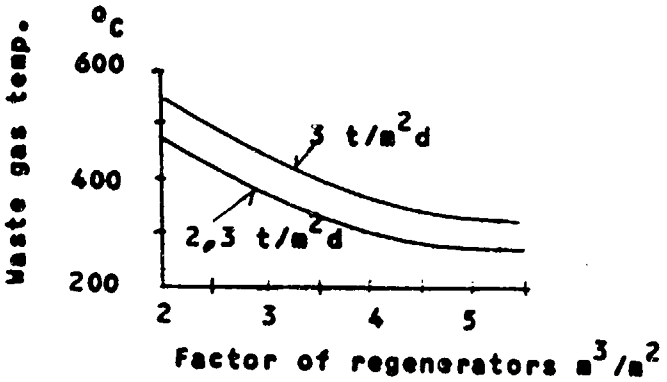

Waste gas temp.
°C
600
400
200
3 t/m²d
2,3 t/m²d
2
3
4
5
Factor of regenerators m³/m²

Fig. 12

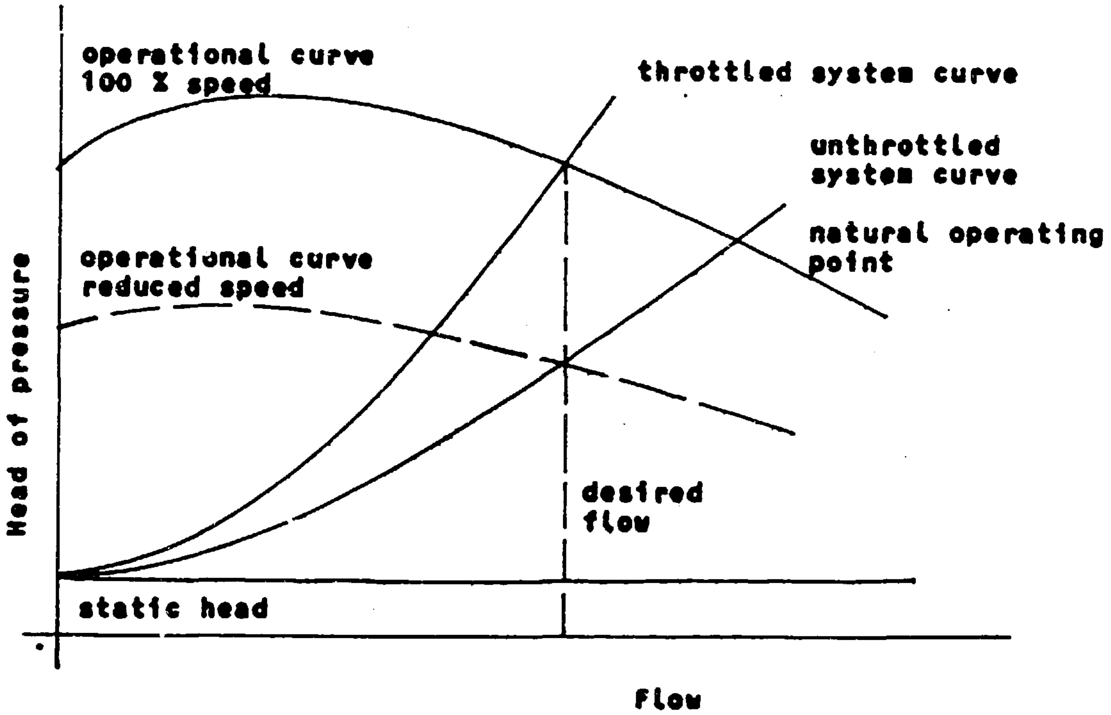


Fig. 16 Operational and system curves

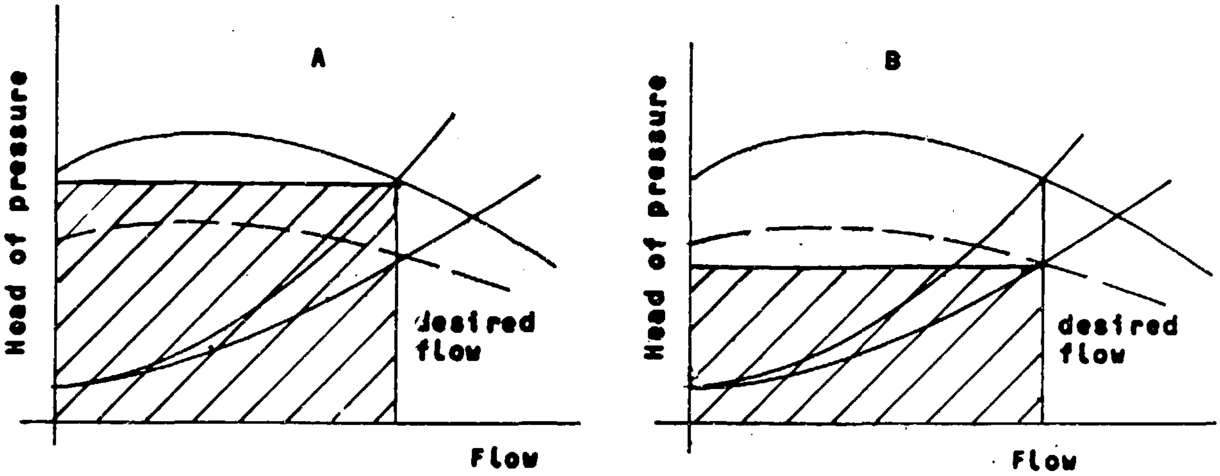


Fig. 17 Power need

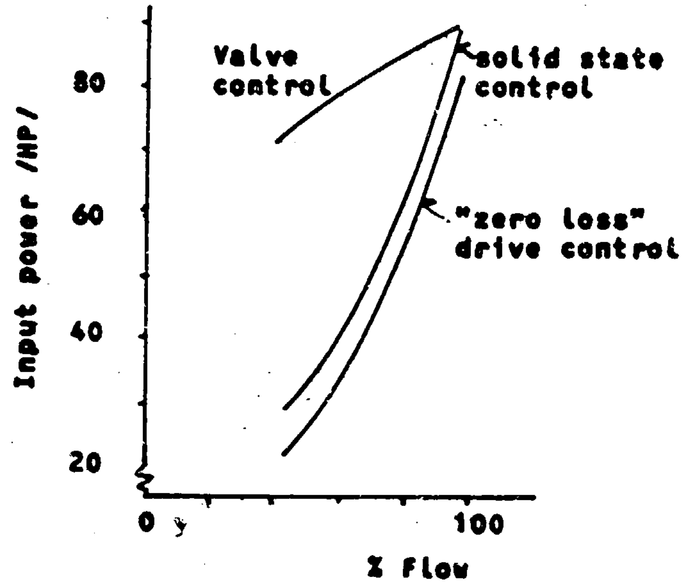


Fig. 18 Input power comparison

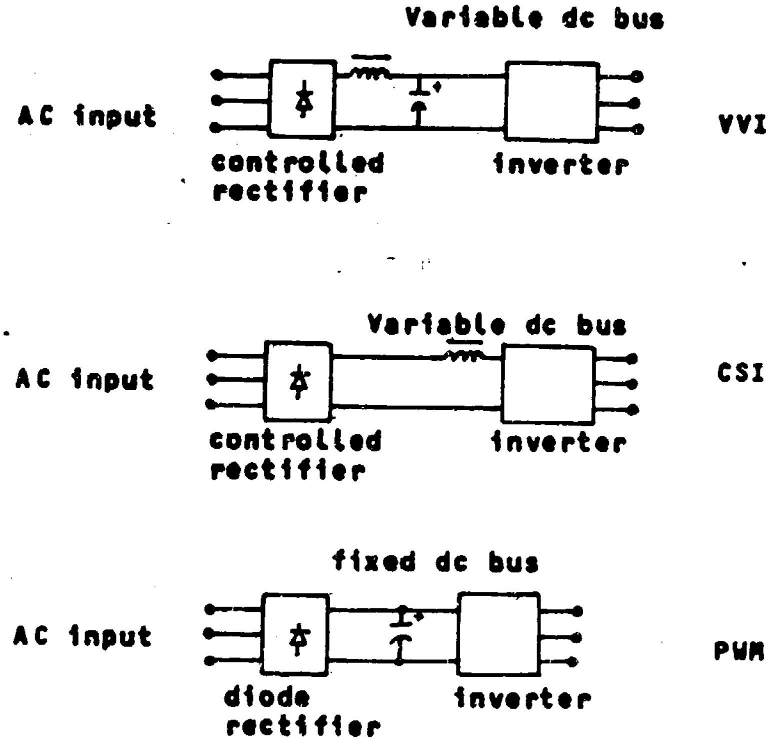


Fig. 19 Schematic drawing for VVI, CSI and PWM drives