Mechanical compression of vapours -An energy saving method

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SUMMARY

In any plant involving concentration of liquids through evaporation or distillation, steam separated from the concentrated product is normally condensed in a condenser (thus losing its entire energy), or is further used in the process (thus utilizing part of its energy). Mechanical compression of steam is achieved with the help of steam compressor, thereby raising the energy of the steam and recirculating the same as heating steam to the evaporator/distillation column and achieving economy in energy consumption.

Mechanical Compression of vapours leads to a considerable decrease in the production cost of a plant and can be used with excellent return on the initial investment in all countries where energy is a porblem.

Figure—1 shows a conventional evaporation process. Heating Steam from an auxiliary boiler or other source is supplied for heating the liquid to be concentrated and bringing it or its boiling point. The evaptoating process could be single or multiple effect. The vapour given off in the last effect of such systems has a very low temperature, say between 45 and 55° C, which is too low to justify addition of an extra effect. This vapour at 45-55°C, is therefore sent to a condensation unit where cooling water removes latent heat (about 568 Kcal/Kg) contained in the vapour. A substantial heat loss results from the latent heat of vapour being transferred to the cooling water. In the cases where condensation takes place by direct contact, thermal and chemical contamination of the cooling water may occur.

In a Mechanical Compression System, shown in **Figure - 2** vapour separated from the concentrated liquid is compressed, thereby raising the pressure, temperature and energy, and recirculated as a heating medium to the evaporation system. Thus, latent heat loss to and contami-

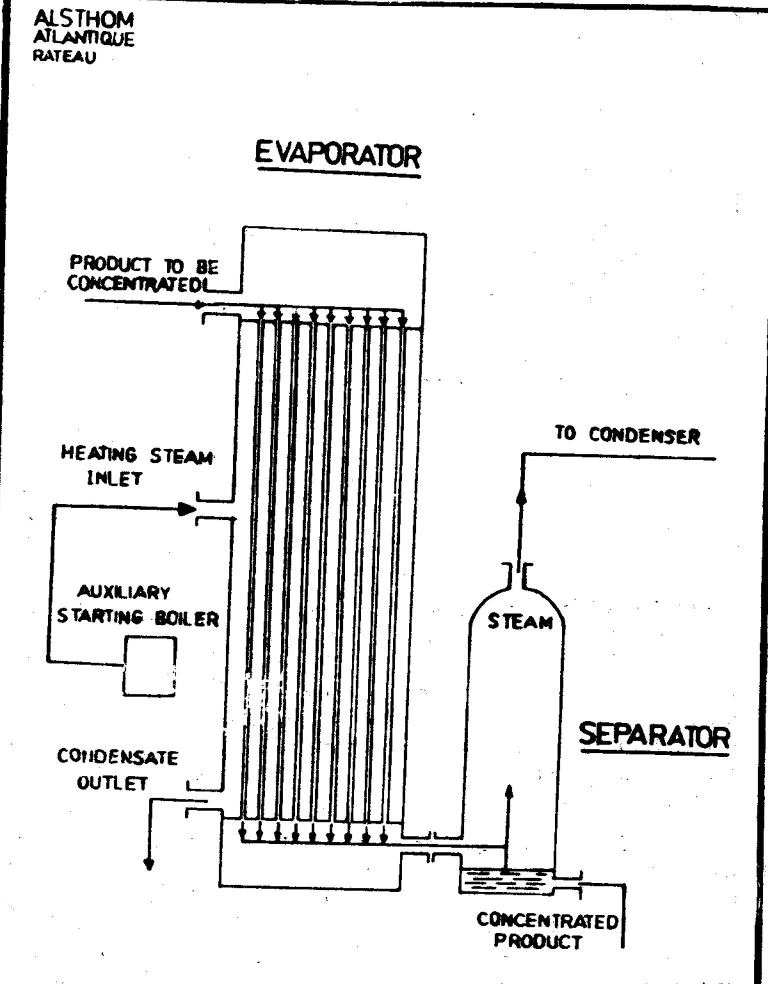

FIGURE - 1 : CONVENTIONAL EVAPORATION PROCESS

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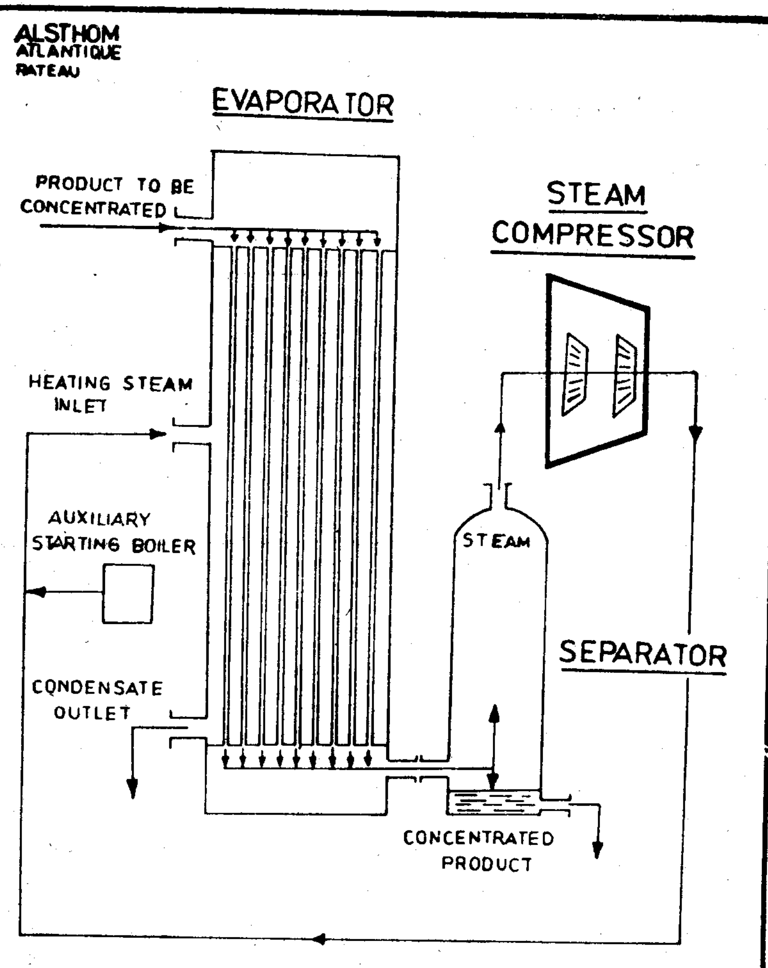

FIGURE — 2 : EVAPORATION PROCESS WITH MECHANICAL COMPRESSION OF VAPOUR

nation of cooling water is avoided. Above all, heating steam is generated within the closed system, thus cutting-off supply from the boiler for the evaporation system' and resulting in a great economy in energy consumption.

Figure—3 shows vapour compression process on Molier (Enthalpy - Entropy) Diagram, while **figure - 4** shows same on Temperature - Entropy diagram. When the vapour to be compressed was otherwise going as waste, input energy of h2'-h1 helps in making available energy h2'--h2s. With compressor efficiency of 75%, values for ten possible cases are as in table-I below for compression of saturated steam.

In case 1 to 5 above increase in saturation temperature of steam is 18 to 20°C, maximum achievable by a single stage compressor. In case 6 to 10, increase in saturation temperature is 35 to 40°C, which can be achieved by a two stage Compressor. Ratio of energy available to energy input varies from 24.06 to 13.55 in case 1 to 5, and from 8.59 to 6.82 in case 6 to 10. This ratio shall very, depending upon inlet conditions for copressor and increase in saturation temperature required.

APPLICATIONS OF CONCEPT

The concept of mechanical compression of vapours can be successfully applied in the following cases :

—Concentration or distillation of Industrial products in :

a. Sugar Mills for concentration of juices and boilings.
b. Distilleries for compression of alcohol vapours of water. vapours (generated by exchanging heat with alcohol vapours).
c. Dairies for concentration of skimmed milk and whey.
d. Chemical and petro chemical plants in numerous distilltion processes, or recovery of low pressure steam.
e. Saltworks for concentration of sodium chloride solution.

— Concentration of particular industrial effluents as pait of pollution control :

a. Paper mills for concentration of black liquors.
b. Distilleries for concentration of residual liquors.
c. Chemical and petro-chemical plants.

— Production of soft water from sea water.

— Any other plant where low pressure vapour is going as waste and recompression of same facilitates saving of energy.

TABLE 1

Sl. No.	Inlet pressure Kg/cm²abs	Outlet pressure Kg/cm² abs.	Enthal pies, h1	h2	Kcal/Kg h2s	Energy input Kcal/Kg. (h2'-h1)	Energy available Kcal/Kg. (h2' - h2s)
1.	0.13	0.20	619.2	643.2	59.6	24	577.6
2.	0.20	050	622.9	673.5	80.9	50.6	580.0
3.	0.50	1.00	631.8	671.8	89.2	40-2	562.6
4.	1.00	2.00	638.7	678.1	119.8	40.4	549.2
5.	2.00	3 60	645.7	683.0	139.7	37.3	498.0
6.	0.15	0.50	620.4	689.2	80.9	68.8	591,1
7.	0.50	2.00	631.8	716.1	119.8	84.3	575.2
8.	1.00	3.50	638.7	717.8	138.6	79.1	559.4
9.	2.00	6.00	645.7	716.8	159.2	71.1	539.8
10.	3.00	8.00	650.0	716.7	171.2	66.7	528.8

MULTI-EFFECT EVAPORATORS WITH THERMO-COMPRESSOR AND MECHANICAL COMPRESSOR

It is a well known fact that in a multi-effect evaporation system, steam consumption (for a given performance) reduces as number of effects increases.

Table—2 below gives average energy consumption for various plants in France with number of evaporation effects varying from one to seven. The energy consumption is expressed in tonnes of oil equivalent (TOE) per annum, the calculations being based on the energy equivalents adopted by the French Energy Economy Agency. To facilitate comparison, units with an evaporating capacity of 10 Tonnes/ Hour have been considered.

It can be observed from Table—2 that passing from a double to tripple effect system means a saving of about 1000 TOE, while passing from a 6 to 7 effects means a saving of

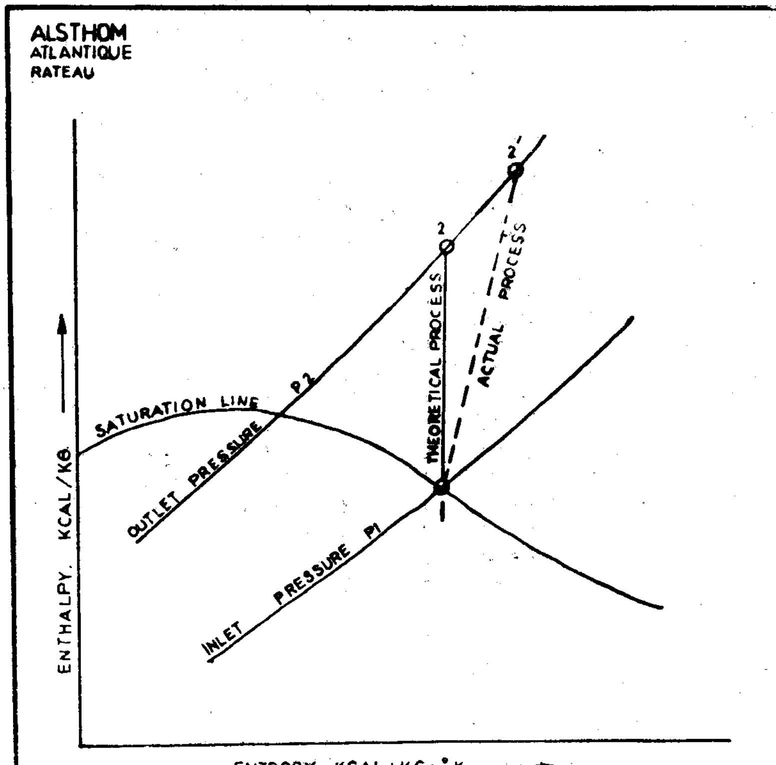

FIGURE-3: STEAM COMPRESSION PROCESS ON MOLIER DIAGRAM

TABLE 2

YEARLY ENERGY CONSUMPTION FOR MULTIPLE EFFECT EVAPORATION SYSTEMS EXPRESSED IN TONNES OF OIL EQUIVALENT (E. O. E.)

Number of Effects	Steam Consumption T/Hr	Hourly Energy Consumption Thermies/Hr	Yearly Energy Consumption Thermies/Year	Annual Consumption T. O. E.
1.	11.5	6,900	55,200,000	5,520
2.	6.1	3,660	29,280,000	2,928
3.	4.	2,400	19,200,000	1,920
4.	3	1,800	14,400,000	1,440
5.	2.5	1,500	12,000,000	1,200
6.	2.1	1,260	10,080,000	1,818
7.	1.85	1,110	8,880,000	888

NOTES
1. Hourly evaporation — 10T/Hr
2. Duration of operation per year — 8000 Hrs
3. 1 Tonne of Steam — 600 Thermies) Average figure allowed
4. 1 KW Hr — 2.5 Thermies) by French Energy Economy
5. 1 T. O. E. — 10,000 Thermies) Agency.

only 120 TOE. The addition of an extra effect to a double effect therefore means an energy saving 8 times higher than that obtained by adding an extra effect to a 6 effect system. The energy savings decrease progressively as the number of effects increases.

Thermo-compression may be used to improve steam consumption in a multi-effect system when steam is available at a pressure much higher than the operating pressure of the first effect of evaporator system. A thermo-compressor normally uses steam at a pressure of 10 to 25 bars, and it draws the vapour given off in the first or second effect (or sometimes even in third effect), and after mixing with live steam compresses it to a pressure sufficient to ensure operation of first effect.

At a relatively low cost, thermo-compression results some saving in steam consumption. However, thermo-compressors

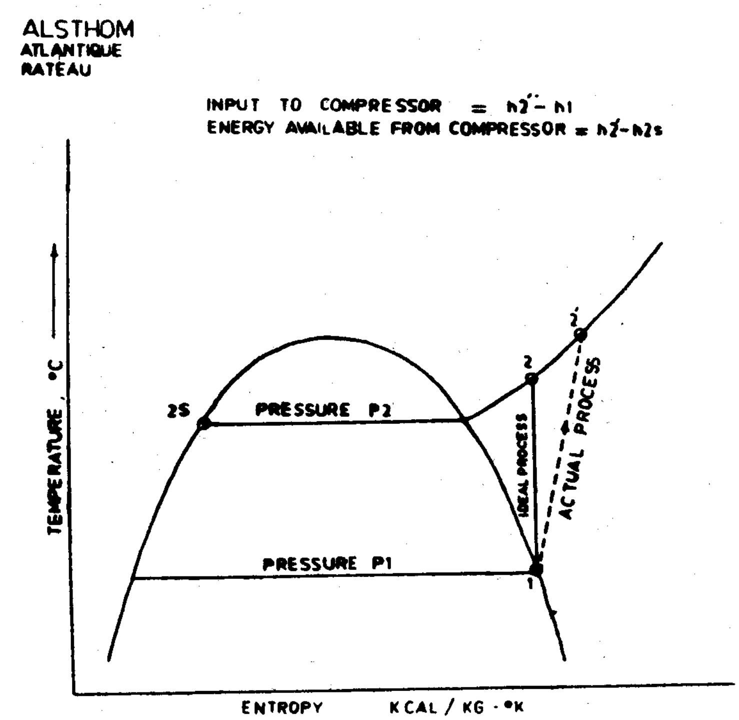

FIGURE- 4 STEAM COMPRESSION PROCESS ON TEMPERATURE ENTROPY DIAGRAM have following limitations :

— Thermo-compressors are practicable when the characteristics of the liquid to be evaporated have boiling laws similar to those of water. When the liquid to be evaporated boils at temperature much higher than water in the same conditions, boiling point rise cannot always be compensated by an equivalent increase in pressure at the outlet of thermo-compressor, because quantity of vapour, that a thermo-compressor can compress, falls rapidly when the delivery pressure increases. Thus, thermo compressors are useful if they can be made to operate with a low compression ratio (ratio of delivery pressure to suction pressure),

— Thermo-compressors require high pressure steam for their operation, which can affect overall steam-power balance of a plant.

— Because steam is mixed with vapour in thermo-compressor, and then fed as heating medium to first effect, condensate from first effect is likely to be contaminated. If this condensate is to be recirculated to boiler, it must be treated appropriately.

— Thermo-compressors are fairly critical in their operation. Once designed for a particular condition, they cannot be run much off the design point, that is load variations can not be accomodated. Hunting or choking can occur with plant instability.

— Thermo-compressors are very sensitive to fouling of heat transfer surface. A small fall in heat transfer coefficient (because of fouling) increases compression ratio, which in turn lowers efficiency of thermo-compressor.

— Entrainment ratio (ratio of quantity of vapour compressed to quantity of steam utilized) achievable with thermo-compressors is low, being in the range of 0.5 to 2.0.

— Lower the suction pressure and higher the compression ratio, lower shall be entrainment ratio. Thermo-compressors cannot draw entire vapour at low pressures.

— Thermo-compressors are not found suitable for evpaporators with large evaporating capacity.

Introduction of a thermo-compressor in a multi-effect evaporation system (say with 6 effects) can amount to addition of say 2 effects.

Mechanical Compressors overcome all the limitations of thermo - compressors. Till oil crisis of 1973, mechanical compressors were preferred for low suction volumes (suction pressure above atmospheric). However, since the past 5 to 7 years, these have been used for a variety of suction and discharge pressures, both below and above atmospheric pressure. Increase in saturation temperature (maximum) available per stage of mechanical compressor is 18 to 20°C.

Table—3 indicates energy consumption for evaporation systems using mechanical vapour

TABLE 3

YEARLY ENERGY CONSUMPTION FOR EVAPORATORS OPERATING WITH MECHANICAL VAPOUR RECOMPRESSION EXPRESSED IN TONNES OF OIL EQUIVALENT (T.O.E.)

Energy used by Steam Compressor for 10 T/Hr of Water Evaporated KW Hr/Hr	Annual Energy Consumption of Steam compressor KW Hr/Year	Yearly Energy Consumption of Steam Compressor T. O. E.
100	800,000	200
150	1,200,000	300
200	1,600,000	400
250	2,000,000	500
300	2,400,000	600
350	2,800,000	700
400	3,200,000	800
450	3,600,000	900
500	4,000,000	1000

NOTES

1. Hourly evaporation — 10 TPH
2. Duration of operation per year — 8000 hrs.
3. 1 T. O. E. — 4000 Kw Hr.

compressors. On comparison of table—2 and 3, it is observed that in a multiple effect system, high energy savings are achieved with mechanical compressors. The lowest energy consumptions with mechanical compressors are 4.4 times lower than the lowest consumptions obtained with a 7 effect evaporation system without recompression. The highest energy consumption (50 KW/Hr per tonne of water evaporated) for mechanical vapour recompression system can be compared with those obtained with 6 effect system.

In France, 4 evaporator bodies and a steam compressor have been found to cost slightly less than 6 evaporator bodies. Similarly, 3 evaporator bodies and a steam compressor have been preferred to 4 evaporator bodies.

Capital cost remaining the same, multi-stage evaporation systems with steam compressor (s) require much less energy consumption and result in appreciable saving in energy every year, thus ensuring excellent return on initial investments.

INSTALLATIONS OF MECHANICAL VAPOUR COMPRESSORS

Adoption of the concept of mechanical compression of vapours in various industrial plants has become important and meaningful since oil crisis of 1973 and further increase in oil prices till 1978/79.

In India, first Mechanical vapour compressor is operating successfully at DCM Mawana Sugar Works, Mawana, District Meerut, U.P. since March, 1984.

Abroad, mechanical compressors have been utilized to save energy in hundreds of process plants, viz. paper plants, Sugar plants, Distilleries, Dairies, Breweries, crystallization plants, Tomato Concentration Plants, Chemical and Petro-Chemical Plants, Water Effluent Treatment Plants, Process Plant Effluent Concentration, Radiactive Waste Concentration etc. Some paper plants abroad have mechanical vapour compressor to concentrate black liquor, where sulphate process is used for producing pulp.

SAVING RESULTING FROM ADAPTION OF MECHANICAL COMPRESSION OF VAPOUR

Various process plants can have different reasons for utilizing a steam compressor. Some plants can use it just to compress low pressure steam, which was otherwise going as waste. Other plants can use the compressor for reducing steam consumption for evaporation, distillation system and utilize the saved steam somewhere else in the plant. Still other plants, which use prime movers exhaust steam for the process, can utilize the compressor to reduce this requirement and facilitate adoption of high pressure high temperature turbines and boilers with much higher efficiency. So same compressor from a supplier can have different benefits for different plants.

The saving resulting from the adoption of this concept is governed by the following factors :—

a. Whether the plant, where the steam compressor is to be installed is an old (existing) plant or a new plant being planned for the future. For an old plant the saving shall be mainly reduction in quantity of the heating steam and associated reduction in energy and fuel consumption. For the plant being planned for the future, saving shall be reduction in capital cost of boiler and its auxiliaries, reduction in capital cost for less number of effects in a multi-effect evaporation system, and lower operating cost because of lesser fuel consumption (resulting from lower consumption of steam for the entire plant), and possibly elimination of cost of condensor and associated equipment like circulating water pumps, air ejectors etc. and in cost of cooling water.
b. Cost of the steam compressor, which is determined by the quantity of steam to be compressed and its inlet and outlet conditions, and materials of construction of the compressor, which are decided by agressiveness of vapour, its solids/water droplet content etc.
c. Whether the compressor shall be driven by a steam turbine or an electric motor, and overall effect of drive on capital investment and energy saving. If steam is available on a continuous basis, steam turbine drive shall be preferred.
d. Cost of energy, i.e. fuel, steam and electricity in the country of installation. Type of fuel, (coal, oil, bagasse etc.) and its cost shall govern cost of energy.
e. Evaporating Capacity of the plant and its operating time (hours per year.)

Savings, in absolute terms, for a particular plant can be determined when the above mentioned details are known. It may please be appreciated that each plant may be unique and to find the best solution it requires close collaboration between the owner (who knows the cost of energy available in his plant), the compressor manufacturer (who can offer the best machine based on previous experience) and the process specialist (who must design a system easy to operate, with the lowest possible energy consumption and perfectly adapted to the chosen compressor). Depending upon type of system and steam compressor installed, return time for investment can be 3 to 24 months. Besides, being an Energy Conservation System, the user is entitled to 100% rebate on investment in the first year itself, and this ensures an attractive tax benefit.

FIRST MECHANICAL VAPOUR COMPRESSOR IN INDIA

Mechanical Vapour Compressor at Mawana Sugar Works (a unit of DCM), Mawana, Distt. Meerut U.P. is first of its kind in India. It is a steam turbine driven compressor. The machine was installed in 1983 and is operating successfully since March, 1984.

This Machine has been supplied by Alsthom Atlantique Rateau, France. a leading supplier of Vapour compressors since 1945. Since 1979, this company has been supplying very compact machines (called SM Compressors) to suit varying requirements of process plants for following applications :—

- Sugar Plants, for concentration of liquors and boilings.
- Paper plants, for concentration of black liquor.
- Distilleries, for compression of alcohol vapour or water vapour.
- Dairies, for concentration skimmed milk and whey.
- Chemical plants (in evporation system), soda ash plants (for reducing steam consumption of process), cyclohexane plants (with distillation columns).
- Concentration of effluent from distilleries, potato treatment plant, wool washing plant.
- Breweries, for recuperation of steam for beer boiling drum
- Saltworks, for concentration of sodium chloride solutions.
- Research loops.

More than 110 machines have been supplied till now, 95 of them since 1980.

Materials of construction are selected depending upon specific application. Depending on agressiveness of vapour, material of casing can be carbon steel, stainless steel (AISI 304, AISI 316, AISI 316 Ti) and that of impeller can be Cr-Ni Steel, Cr-Ni-Mo-Mn steel etc.

Steam compressors from Alsthom Atlantique Rateau are suitable to handle suction volume (per stage) from a few thousand M^3/Hr to 180,000 M^3 Hr. Increase in saturating temperature (maximum) achievable per stage is 18 to 20°C. Two or more stages can be used in series for achieving higher increase in saturation temperature, and in parallel to handle larges volumes of vapour. Biggest steam compressor supplied till now has been for a paper plant (for pre-concentration of black liquor) with following parameters :

- Suction pressure 0.2726 ata
- Discharge pressure 0.4170 ata
- Suction flow 175 000m^3/Hr (32,016 Kg/Hr)
- Speed 4718 RPM
- Power Consumption 774 KW (Motor driven)
- Type SM-120-1 (Single impeller of 120 cm diameter)

Compression stages of SM Compressors are mounted on a step-up gear with parallel gear trains. Each stage has a stator bolted to the casing of the step-up gear and rotor basically consisting of a high-performance, open radial impeller cantilevered on the high-speed shaft of the step-up gear, Stator intake section can accomodate a variable-pitch blading device to control output. Compressor and its step-up gear form a complete assembly including the lube oil and sealing systems.

SM Compressors can be driven by an electric motor (1500/1800/3000/3600 rpm) or a steam turbine. A motor driven compressor can have maximum four stages of compression on same gear box, while steam turbine driven compressor can have maximum three stages. More stages can be had with more than one gear box.

Turbo-compressor at Mawana has been designed to compress vapours from outlet of vapour cell (vapours going to vacuum pans) to inlet of vapour cell, as well as from outlet of first effect to inlet of vapour cell. Operating conditions in the two cases are as below :

	Case—1	Case—2
Compressor		
—Flow, Tonnes/Hr	20	20
—Inlet pressure, ata	1.2794	0.9982
—Inlet temperature, °C	106.1	99
—Discharge pressure, ata	2.0176	2.0176
—Discharge temperature, °C	158	181
—Speed, rpm	11980	14950
—Power input, KW	623	978
Steam Turbine		
—Steam inlet pressure, barg ...	30.338	±0.689...
—Steam ,nlet temperature, ° C...	385	±3.9......
—Back Pressure, bar g	...1.034 ...	... ...
—Steam consumption, Tonnes/Hr	6.7	8.9
—Speed, rpm	14645	18275

At present, machine is operating under conditions of Case-1 Turbo-Compressor at Mawana has achieved the following benefits for the plant :

- Conservation in use of furnace oil in early part of crushing season, when bagasse produced was low.
- Maintaining higher sustained crush (8 to 12% higher than rated value of plant)
- Reduction in overall steam consumption for plent by about 1 to 1.5% on cane (say 3 Tonnes/Hr), with present evaporation system and scope of higher savings with future improvement in evaporation system.

RECOMMENDFD LOCATION OF MECHANICAL COMPERSSOR IN EVAPORATION SYSTEMS

In many large size evaporation plants, mechanical compressors have been used as pre-concentrators before finishing concentration of product in conventional tubular or plate multi-effects. However, location can vry depending upon overall techno-economic feasibility.

COST SAVING SYSTEMS ASSOCIATED WITH MECHANICAL COMPRESSORS

Industrial plants short of power and requiring mechanical compressor to conserve steam, cae utilize a steam turbine driven compressor with facility of power generation. As shownin Figure 5, compressor and turbine shall be mounted on two high speed shafts of gear box, while alternator shall be mounted on low speed shaft. High pressure steam is to be made available for driving the turbine, which shall be designed adequately to produce power for compressor and alternator. Such systems are available from Alsthom Atlantique Rateau, France. All kind of load variations for compressor and alternator can be met by the offered system.

Turbo-compressor at Mawana also has provision of power generation (1000 KW). though

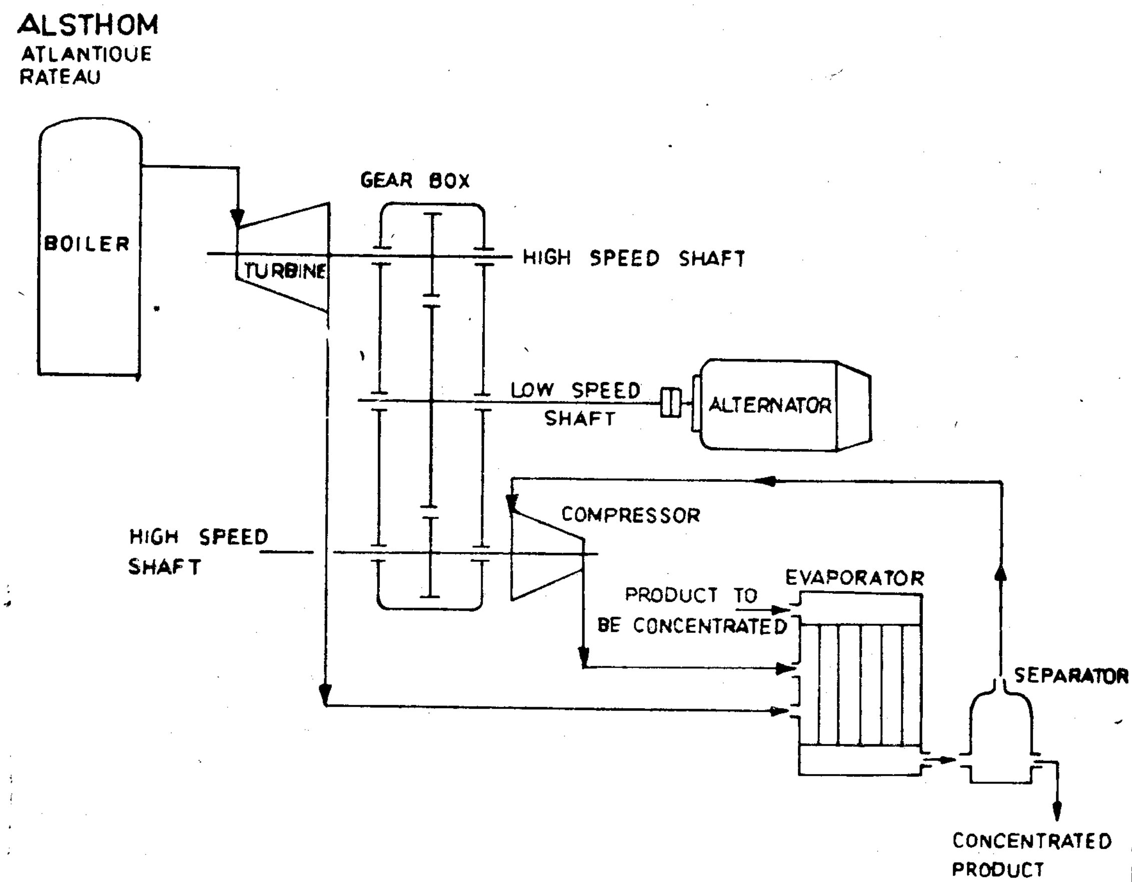

FIGURE-5 :— MECHANICAL VAPOUR COMPRESSION SYSTEM WITH FACILITY OF POWER GENERATION at present power is not being generated.

For Process Plants in India, where mechanical vapour compressor can be incorporated, such systems not only reduce operating cost, but also capital cost by eliminating almost complete cost of a power turbine. Moreover, continuous availability of power is also ensured and dependence on external power supply is eliminated.

IMPORT PROCEDURE

Mechanical vapour compressors not being manufactured in India at present, these are to be imported. Ministry of Industry has created Technical Development Fund to cover foreign exchange requirement for proposals aimed at technology upgradation, cost reduction, modernisation and rationalisation etc. The aggregatc foreign exchange financed for any unit under ths scheme is limited to US $ 5 lakhs equivalent per year (more than 60 lakhs rupees).

Application for import should be made to the special Committee for Technical Development Fund, Department of Heavy Industry (R & I Section), Udyog Bhavan, New Delhi. Complete details are given in Handbook of Import-Export Procedures, 1984-85, chapter 5, page 31 para 127 to 131.

Import licence is normally given within 45 days.

CONCLUSIONS

The concept of mechanical compression of vapours has been successfully adopted as an energy saving method in a number of Industrial Plants throughout tne world. The concept holds a good promise for every country where economy in energy consumption is valued.

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