(12) UK Patent Application (19) GB (11) 2 074 463 A

(21) Application No 8113223
(22) Date of filing 29 Apr 1981
(30) Priority data
(31) 3016406
(32) 29 Apr 1980
(33) Fed Rep of Germany (DE)
(43) Application published 4 Nov 1981
(51) INT CL³ B01D 1/28
(52) Domestic classification B1B 302 303 403 501 502 B
(56) Documents cited
GB 1515048
GB 1047981
GB 663862
GB 652888
GB 512657
(58) Field of search B1B

(71) Applicants
Maschinenfabrik Buckau R. Wolf Aktiengesellschaft,
4048 Grevenbroich 1,
Lindenstrasse 43,
Germany

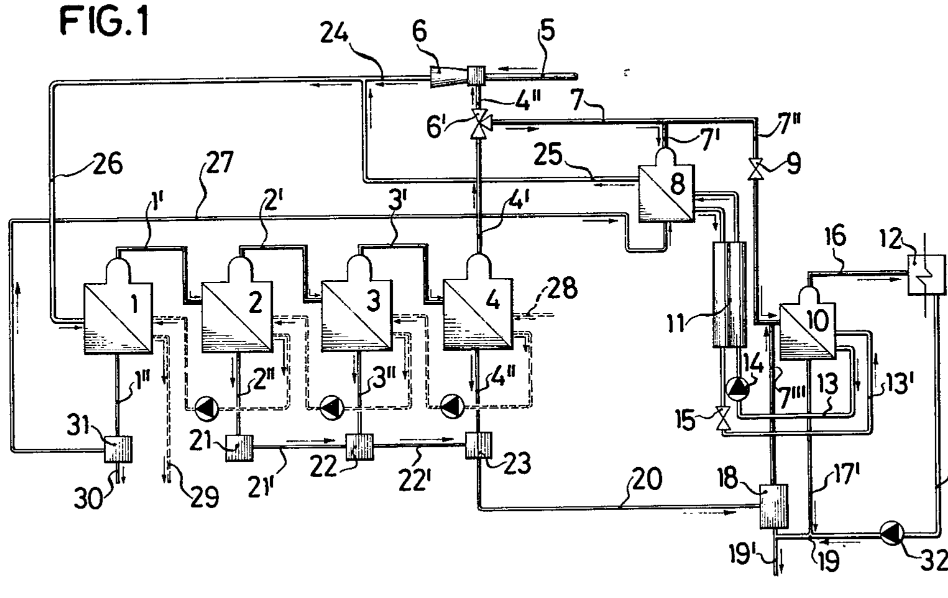
(72) Inventor
Paul Franzen

(74) Agents
Haseltine Lake & Co.,
Hazlitt House,
28 Southampton Buildings,
Chancery Lane,
London WC2A 1AT

(54) Multi-stage vaporiser having a heat-recovery system

(57) A multi-stage vaporiser having a vaporiser section (1-4) and a heat-return section (6, 8, 10, 11 etc) by means of which heat contained in the vapours of the vaporiser section are at least partially reconverted into useful heat. The temperature of the useful heat is significantly above the temperature of the vapours, the heat-return section including a vapour compressor, which may be a steam jet nozzle, and an apparatus incorporating a heat-transformer. The heat-transformer raises the temperature of a given heat flow to a higher level by using heat as a motive energy, for example, by utilising a complex mixture which gives off heat as it absorbs vapour.

FIG.1



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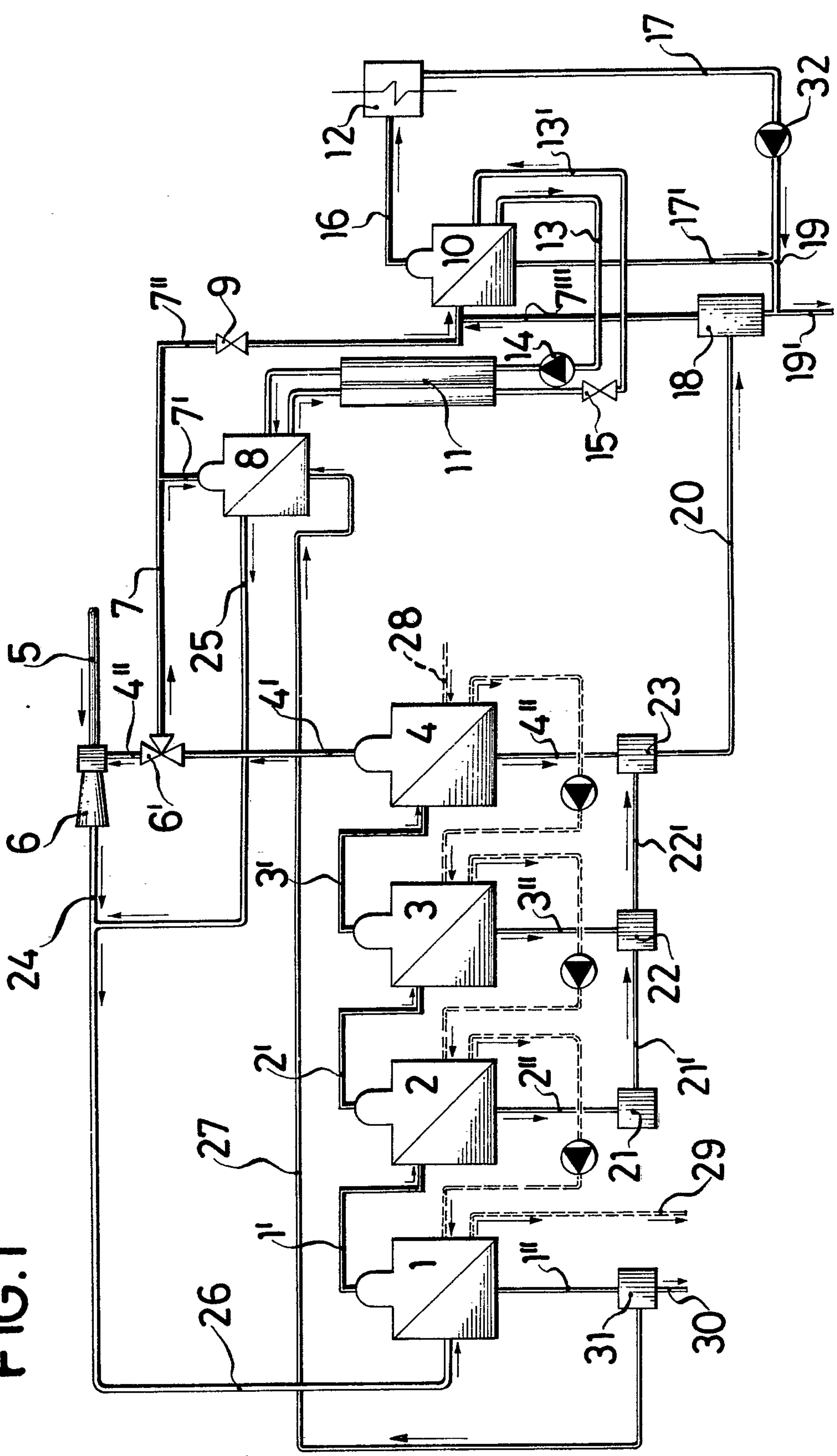
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FIG.1

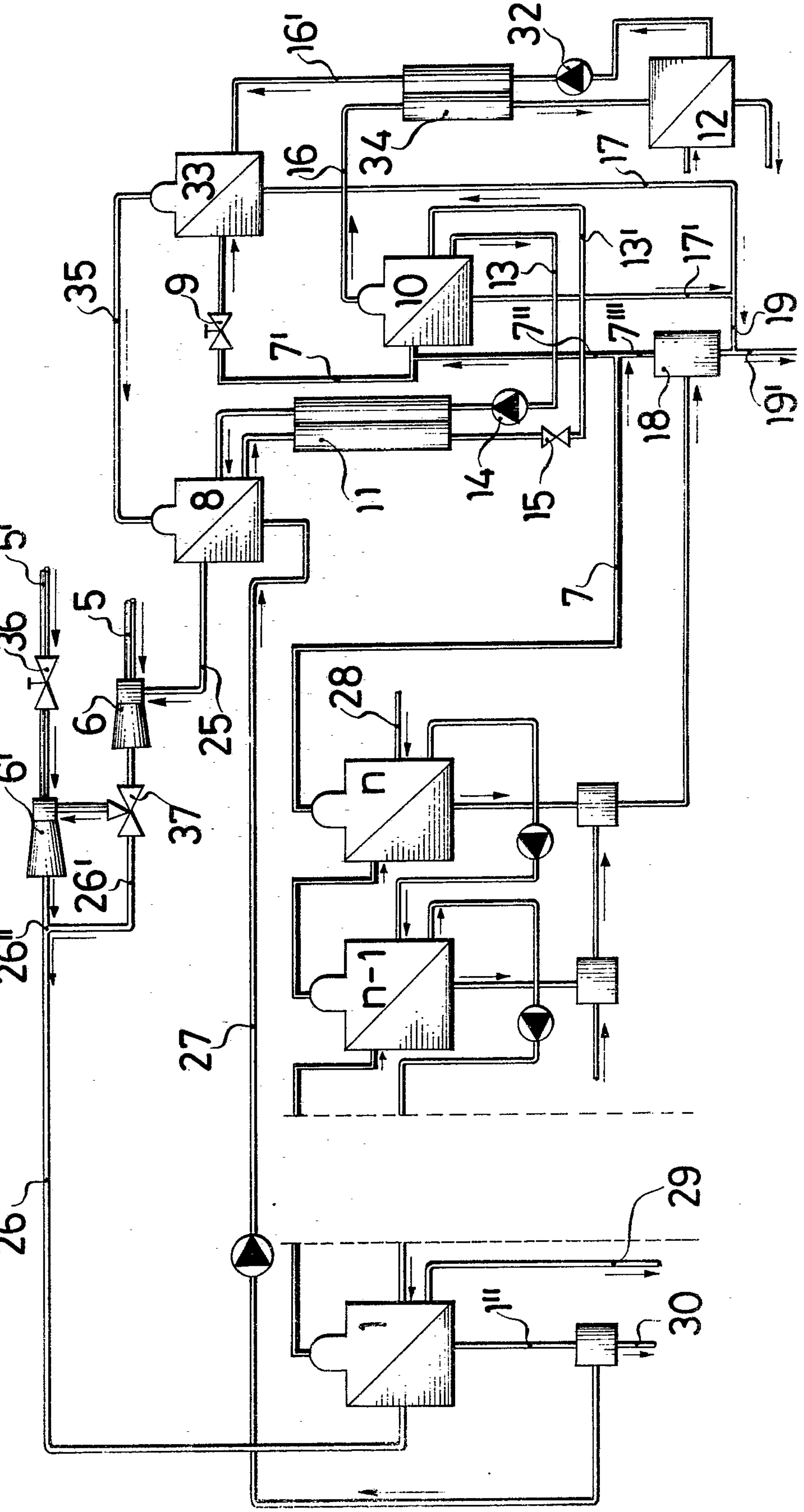
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FIG.2

SPECIFICATION

Multi-stage vaporiser having a heat-recovery system

This invention relates to a multi-stage vaporiser having a heat recovery system, which combines with one another vapor compressors and apparatus operating in accordance with a heat transformer principle. The heat recovery system utilises the heat energy present in evaporated liquid vapours leaving the last vaporiser stage(s) of the apparatus so that the heat energy can be increased in value with minimal use of additional energy to process heat level and can be supplied again to the initial vaporiser stage(s) as process heat. Such multi-stage vaporisers are used in thermal processing techniques, for example, to increase the concentration of solutions or in distillation processes and serve in this connection to save energy.

In order to lower the demand for processing or working energy in connection with processes for thermally separating substances, multi-stage vaporiser plants, vaporiser installations with vapour compressors or combined multi-stage vaporisers with vapour condensers are at present used. The saving in energy in connection with multi-stage vaporisers is achieved by the fact that the heat contained in the vapours produced in the individual evaporating stages is utilised for heating the next respective stage. The vapours of the final evaporator stage are liquefied in vapour condensers and the condensate is freely discharged, since any economic use of the heat which is contained in these vapours is usually impracticable. The evaporation enthalpy of the vapours may possibly be utilised for preheating the solution to be concentrated by evaporation. However, since this is always greater than the heat quantity which can be transferred to the solution which is to be heated, the major part of the heat of the vapours has to be discharged, without being used, into the ambient temperature.

The optimum number of evaporator stages and thus the possible saving of energy in connection with multi-stage vaporisers is determined by the technical, thermodynamic and also the economic profit margin conditions, since the procedures for concentration by evaporation are only able to take place within defined temperature intervals, which are established by the material properties, the process steam temperatures which are available and the data concerning the substances of the solutions which are to be concentrated by evaporation.

Furthermore, the expenditure for investment and maintenance, with an increasing number of stages, rises in an amount which is greater than is proportional to the saving in energy.

Another possibility of economically introducing high-grade energy in connection with vaporising processes is for the vapours of the evaporated liquids to be compressed by mechanical compressors or steam-jet blowers to a higher heating steam pressure and them to be again supplied as process steam to the vaporiser. Vapour compression with mechanical compressors is, however, only appropriate economically and thermodynamically if the throughput of steam or vapour is high and the ratio between vapour pressure and heating steam pressure is as small as possible. With vaporisers which have been developed, the favourable temperature difference between vapours and heating steam is in the range from 10K to 20K, while mechanical vapour compressors operate uneconomically above this temperature difference.

Instead of using mechanical compressors, which are expensive and frequently require extensive maintenance, it is possible to use steam-jet devices, which are less expensive, but more robust. For each Kg of vapour, the jet compressor requires a considerable quantity of driving steam, which is greater in proportion as the temperature difference between the evaporated liquid vapour and driving or live steam is smaller. However, since the amount of heating steam which is required does not considerably exceed the amount of vapour, it follows therefrom that it is possible in this way for only a part of the evaporated liquid vapour to be compressed, whereas the residue, if it is not to be used in some other way, has to be discharged as waste heat into the atmosphere.

Accordingly, since with increasing difference in temperature between evaporated liquid vapour and heating steam, the consumption of energy for the operation of the compressors and/or the technical expense increase considerably, a combination of multi-stage evaporators and vapour compressors, with the object of utilising as far as possible in the evaporator section the temperature difference between process steam and ambient temperature in order again to raise process steam level, the lowest possible vapour temperature in the last stage by means of vapour compressors is uneconomical and is wasteful of energy. Thus, the advantages of the one system — saving of energy in the multi-stage vaporiser by utilising the large difference in temperature between the vapours of the last evaporator stage and the heating or process steam for the first evaporator stage — are able completely to balance the advantages of the other system — in the vapour compressors the smaller the temperature difference between vapours and heating steam, then the smaller is the expenditure for energy.

It is an object of the invention so to use the vapour heat with vaporisation processes for the preparation of process heat by means of a suitable procedure and an apparatus for carrying the latter into effect that it is possible to have recourse to the advantages of the vapour compression without having to forego the advantages of multi-stage vaporisers.

According to one aspect of the present invention, there is provided a multi-stage vaporiser having a vaporiser section and a heat-return section, by means of which heat contained in the vapours of the vaporiser section are at least partially re-converted into useful heat, the temperature of which being significantly above the temperature of the vapours, the heat-return section including a vapour compressor and an apparatus incorporating a heat transformer.

According to a second aspect of the present invention, there is provided a method of vaporising liquids using a multi-stage vaporiser that is essentially as defined in the preceding paragraph.

A heat transfer may essentially be defined as means to raise the temperature of a given heat flow to a higher level by using heat as motive energy. For example, a process is supplied with heat at a medium temperature as motive energy. Part of this heat is given off at a low temperature, which is higher than or is equal to the ambient temperature, while the rest is transformed to a temperature level, which is noticeably higher than the temperature of the input heat.

With the present invention, part of the evaporating liquid vapours from the last or from one of the last vaporiser stages can be supplied to a steam-jet device or nozzle and part of the vapours which cannot be compressed in the steam-jet device are supplied to the heat transformer section, where the heat thereof is raised, at least partially, to a higher temperature, but more especially to the temperature level of the vapour of the mixture downstream of the steam jet device. If the temperature difference between the evaporating liquid vapours and the heating steam temperature in the first or one of the first evaporator stages is larger than that which can be bridged by the heat transformer section by itself, all the evaporating liquid vapour from the last or from one of the last vaporiser stages can be supplied to the heat transformer section and the steam at higher temperature which is produced in the heat transformer section is thereafter compressed with vapour compressors to processing steam level.

The heat transformer section, in which the vapour heat is raised, at least partially, without appreciable use of higher grade energy to a higher temperature level, but which serves more especially for the generation of steam, can be developed in an interengaged constructional form, i.e. the evaporating liquid vapours are absorbed by the operating mixture of substances circulating in the heat transformer section as more readily volatile components — the so-called working medium — and is again vaporised from the latter at low pressure.

Suitable as mixtures of working substances, in the heat transformer section for vaporiser plants in which, for example, water is evaporated, are mixtures of LiBr — H_2O, NaOH — H_2O or KOH — H_2O. It is likewise possible for the heat transformer section to be developed in a coupled construction. In this case, the flows of substance passing through the vaporiser section and circulating in the heat transformer section are completely separated from one another.

The heat transformer section and the vapour compressor section can be so connected to one another that the amounts of evaporating liquid vapour to be supplied to the two sections can be regulated independently of one another, more especially the vapours being possibly all supplied to the heat transformer or all being supplied to the vapour compressors. In addition, for the purpose of a greater increase in temperature, the heat transformer section can be so connected to the vaporiser section that the vapours used for heating the expulsion stages can be derived from a stage other than that of the vaporiser section, which is connected by way of a vapour pipe to the absorber. With the heat transformer in a coupled constructional form, this effect is produced by the expulsion stages and the working medium vaporiser or vaporisers of the heat transformer being heated with vapours of different temperature.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:—

Figure 1 is a diagrammatic view showing one form of vaporising apparatus having an integrated heat transformer section and a steam jet blower or nozzle operated in parallel therewith, in association with a four-stage vaporiser, and

Figure 2 is a view similar to Figure 1 of a second form of apparatus.

In the form of apparatus illustrated in Figure 1, four evaporator stages 1, 2, 3 and 4 are connected to one another in series by pipes 1′, 2′ and 3′, respectively, to form a multi-stage vaporiser. The vaporiser is supplied with processing steam (i.e. steam to effect vaporisation) by way of a pipe 26 and the evaporated liquid passes from one stage to the next through the vapor pipes 1′, 2′ and 3′. The apparatus also has a steam jet device or nozzle 6, a vapour absorber 8, a vapour expulsion unit 10, a heat exchanger 11 and a condenser 12.

The vapour formed in the last evaporator stage 4 is supplied by way of a pipe 4′ to a distributing valve 6′, which is connected by way of a pipe 4″ to the steam nozzle 6 and by way of a pipe 7 and then pipes 7′ and 7″, to the heat-delivery side (absorbtion side) of the absorber 8 and to the heat-delivery side of the expulsion unit 10, respectively.

Some of the vapour in the pipe 4′ passes by way of pipe 4″ into the steam nozzle 6 and is compressed therein by means of live steam fed from a pipe 5 to the processing steam pressure. The remainder of the vapour in the pipe 4′ passes into the pipe 7; the quantity of this vapour is mainly determined by the enthalpy values of the liquid vapour from the stage 4 and the live steam from the pipe 5 and also by the efficiency of the steam nozzle 6.

The vapour in the pipe 7 is fed into the absorber 8, in which it is absorbed by a suitable substance which can absorb the vapour to generate heat, this substance being present in the absorber 8. The vapour in the pipe 7 is also fed into the expulsion unit 10, where it supplies, by condensation, heat to the substance just mentioned, which has been drawn off from the absorber 8 by way of a pipe 13′ in order to regenerate it, after it has performed its vapour absorption function, by driving off the absorbed vapour.

Steam is also supplied to the expulsion unit 10 by way of an additional supply pipe 7‴, this steam being derived from a condensate-expansion vessel 18, into which condensate from the evaporator stages 2, 3 and 4 and collected in collecting vessels 21, 22 and 23, respectively, is introduced by way of a pipe 20. A regulating valve 9 in the pipe 7″ serves for adjusting the quantities of vapour respectively fed to the absorber 8 and expulsion unit 10.

Heat formed in the vapour absorber 8 is utilised to form steam from condensate fed through a pipe 27 from a condensate-collecting vessel 31 of the first evaporator stage 1. This steam is fed through a pipe 25 to join the steam or vapour pipe 24. The steam or vapour from the pipes 24 and 25 is supplied jointly by way of the pipe 26 to the first vaporiser stage 1 as processing steam.

The formation of heat in the absorber 8, as mentioned above, is achieved by use of a certain type of substance which is continuously supplied to the absorber by way of a pipe 13, this substance being an unsaturated complex mixture which absorbs the evaporating liquid vapour introduced by way of the pipe 7′ and with evolution of heat, to the state of saturation. The saturated mixture is drawn off from the absorber 8 by way of the pipe 13′ to a heat exchanger 11 where it heats a cooler mixture in the pipe 13 and, after being throttled in a reducing valve 15, is supplied to the expulsion unit 10. There, the evaporating liquid vapour taken up by the complex mixture in the absorber 8 is again driven off at lower pressure by heat absorption from the hot vapours which pass into the expulsion unit 10 by way of the pipes 7″ and 7‴.

The complex mixture as thus regenerated is extracted from the unit 10 through the pipe 13 and is pumped back by means of a pump 14 and, after further heat absorption in the heat exchanger 11, is fed again into the absorber 8. The vapour which is driven off from the complex mixture is drawn off from the expulsion unit 10 *via* a pipe 16 and is condensed in a condenser 12 at comparatively low temperature, e.g. ambient temperature. The condensate formed in the condenser 12 is drawn off by way of a pipe 17, is mixed with condensate formed in the unit 10 and drawn off into a pipe 17′, and, by way of a pipe 19, is mixed with condensate drawn off from the condensate-expansion vessel 18.

It will thus be seen that the parts of the apparatus just discussed work on the heat transformer principle.

An example of the use of the apparatus in accordance with Figure 1 will now be given.

An aqueous solution of which the concentration is to be raised passes in succession through the evaporator stages 4, 3, 2 and 1, in that order. The temperature of the heating steam for the first stage 1 is 110°C, and the vapour which leaves the final stage 4 has a condensation temperature of 70°C. Saturated steam at a temperature of 200°C is available in the pipe 5. The temperature of the cooling medium is 15°C in the condenser 12.

With the conditions as indicated as regards temperature and pressure, approximately 0.27 kg of evaporating liquid vapour, which leaves the stage 4 at a pressure of about 0.31 bar$_g$, are able, per kg of live steam, to be compressed to 1.43 bar, corresponding to 110°C. The excess vapour is conducted into the heat transformer section. Approximately 52% of the excess vapours pass by way of the pipe 7′ into the absorber 8, to which is simultaneously supplied an aqueous solution, for example, a mixture of lithium bromide and water with about 62.5% lithium bromide, or caustic soda solution with about 57.5% NaOH, at a pressure P_A — 0.31 bar, by way of the pipe 13. The evaporating liquid vapour is absorbed by the lithium bromide water mixture or the caustic soda solution and with evolution of heat to the point of saturation; the saturated mixture is drawn off by way of the pipe 13′ and after giving off heat in the heat exchanger 11, is throttled in the throttle valve 15 to the pressure P_H — 0.023 bar$_g$ and supplied to the expulsion unit 10. As a result of the absorption heat being developed, which heat becomes free in the absorber 8 at a mean temperature of about 114°C, the heating steam condensate which is introduced by way of the pipe 27 and of which the temperature is assumed to be 100°C, can continue to vaporise and the vapour with a temperature of about 110°C is able by way of the pipe 25 to be mixed in the pipe 24 with the steam leaving the steam-nozzle 6.

The enriched mixture of substances passed by way of the pipe 13′ into the expulsion unit 10 is brought into heat-exchanging contact with the steam introduced by way of the pipes 7″ and 7‴. In this connection, the evaporated liquid vapour taken up in the absorber 8 is again driven out of the mixture at a temperature of 65°C, is supplied by way of the pipe 16 to a condenser 12 and is liquefied in the latter at a temperature of 20°C. The regenerated mixture, which contains about 5% less water than the saturated mixture after the absorption process, is extracted from the expulsion unit 10, is conveyed by means of the pump 14 into the heat exchanger 11, in which it is heated up to practically the initial temperature of the absorber 8, and thereafter passes in a reverse direction into the absorber 8. The ratio between the quantity of steam or vapour transported in the pipes 7″ and 7‴ and that transported in the pipe 7′ amounts to approximately 1.2:1.

With the apparatus as illustrated, it is possible, using the assumed temperature and pressure conditions and also the stated processing conditions, and with an input of 1 kg of live steam at 200°C, to produce approximately 2.20 kg of heating or process steam at a temperature of 110°C for the first vaporiser stage 1. This corresponds to a specific steam consumption for the entire installation of 0.136 kg of steam per kg of vaporised water, this being a value which is about 55% lower than than which can be achieved for comparable four-stage vaporisers without a heat-recovery system or that which can be theoretically achieved only in a nine-stage vaporiser.

In a further example, a solution, of which the vapours from the last stage are not suitable for being used for thermocompression, is concentrated by evaporation in a multi-stage vaporiser. The temperature of the heating or process steam for the first stage is 130°C and the condensation temperature of the vapours from the last stage is 70°C. Available as processing steam is superheated steam at 16 bar$_g$ and a temperature of 215°C. The coolant temperature is 15°C.

The heat-return section is designed in accordance with Figure 2; as compared with the arrangement which is shown in Figure 1, the heat transformer section has, as a main distinguishing feature, an additonal vaporiser 33, an additional heat exchanger 34 and connecting pipes 16′ and 35, which respectively connect the vaporiser 33 to the condenser 12 and to the absorber 8.

The evaporating liquid vapour in pipe 7' is thus not conducted directly into the absorber 8, but is used for vaporising the more readily boiling components which are driven off in the expulsion unit 10, are thereafter liquefied in the condenser 12 and are conveyed with the pump 32 into the evaporator 33. It is certainly true that, as compared with the equipment which is described in the first example, this connection procedure is more costly as regards equipment and is somewhat less favourable as regards energy, but greater freedom is given as regards the choice of the absorption mixture, since the evaporating liquid vapour is not simultaneously used as working medium for the absorption process. It is thus possible also to use the thermal content of vapours which are either heavily charged with foreign substances or for which it is not possible to find any suitable absorption partners.

Selected as a pair of suitable working substances is a mixture consisting of ammonia and water, in which ammonia appears as the more readily boiling component, which is driven off in the expulsion unit 10 at a temperature of 65°C, is liquefied in the condenser 12 at 20°C, is thereafter vaporised in the vaporiser 33 at 65°C and, in the absorber 8 under a pressure $p = 27\ bar_g$, is again absorbed by the weaker concentrated solution from the pipe 13. The concentration of ammonia after the expulsion procedure amounts 46%, and this after the absorption procedure is 51%.

On the assumption that the hot water flowing to the absorber 8 by way of the pipe 27 is approximately at boiling temperature with a pressure of 1 bar, approximately 0.41 kg of saturated steam with the temperature 100°C are produced with the apparatus as illustrated per kg of evaporating liquid vapour, which is supplied to the transformer section by way of the pipes 7', 7" and 7'". This steam is compressed in the steam nozzle 6 by the live steam from the pipe 5 (16 bar_g, 215°C) to 2.7 bar, corresponding to a saturation temperature of 130°C. The quantity of live steam required for this purpose amounts to about 2.1 kg per kg of intake steam drawn in through the pipe 25. Consequently, per kg of processing steam of the state as indicated above, altogether 1.48 kg of heating or processing steam of 130°C are prepared for the first evaporator stage. This corresponds to a lowering of the specific steam consumption of 32% as compared with that required for a multi-stage vaporiser, which operates with the same number of stages without the heat-return section as described in the temperature range of 130°C/70°C.

In the stationary condition, the steam-nozzle 6 is inoperative and the valve 37 is only opened to the pipe 26. In the event of the operating conditions changing, for example, with the starting up of the apparatus, with lowering of the vapour temperature or with lowering of the quantity and/or temperature of the steam in the pipe 25, the steam nozzle 6' is additionally brought into operation, to which live steam in the same state as that in the pipe 5 is supplied by way of the pipe 5'. The steam nozzle 6' is thus able to be so operated that the pressure of the mixed steam only differs to an insignificant degree from that of the intake steam and thus the apparatus serves only for regulating quantities, but it may also be so designed that here the mixed steam leaving the first steam nozzle is once again compressed for the purpose of a further significant raising of the temperature.

The advantages which are produced by means of the invention consist more especially in that the heat quantity which is recovered is available as processing steam, which can be once again used in the process itself. As a result, the expense for primary energy in respect of the vapourising process is reduced considerably as compared with known multi-stage vaporisers having an equal number of stages and the same output as the present apparatus. The invention permits the combination of the advantages of multi-stage vaporisers with those of vapour compressors, without the utilisation of the advantages of the one process having a disadvantageous effect on the operating procedure of the other process. As an amplification in respect of the two examples as illustrated, it is naturally also possible to influence the hitherto used method of vapour compression with steam-jet compressors in an advantageous manner, by a portion of the vapours from the first vaporiser stage being compressed in known manner with the aid of a steam-jet compressor, for the mixed steam of the first stage to be again supplied to the heating side and for the excess vapours to be conducted into other vaporiser stages, which are combined with a heat transformer. In this respect, the steam generated in the heat-transformer section is supplied with the excess vapours from the first vaporiser stage to the second vaporiser stage.

An additional advantage of the process consists in the reduction of the thermal environmental loading and thus in the reduction in the investment and operating costs for the cooling means which are necessary in connection with thermal processes.

CLAIMS

1. A multi-stage vaporiser having a vaporiser section and a heat-return section, by means of which heat contained in the vapours of the vaporiser section are at least partially re-converted into useful heat, the temperature of which being significantly above the temperature of the vapours, the heat-return section including a vapour compressor and an apparatus incorporating a heat transformer.

2. A vaporiser as claimed in claim 1 and a method of carrying out the process performed by the vaporiser, wherein the vapours from one or more vaporiser stages are partially supplied to said vapour compressor, which is a steam jet compressor, and partially to said heat transformer.

3. A vaporiser as claimed in claim 1 and a method of carrying out the process performed by the vaporiser, wherein the vapour of evaporated liquids from one or more vaporiser stages is supplied as a whole to said heat transformer, is at least partially converted therein, without appreciable use of energy of a higher grade, into steam of a higher temperature and is thereafter compressed in said vapour compressor to the required process vapour pressure.

4. A vaporiser and a method as claimed in claim

1, 2 or 3, wherein steam leaving the vapour compressor is admixed with process steam for the operation of the vaporiser section.

5. A vaporiser and method as claimed in any one of the preceding claims, wherein steam is supplied to said vapour compressor as driving steam by way of a by-pass pipe and wherein high pressure steam not flowing through the by-pass pipe is brought to process steam pressure level, either by means of an additional vapour compressor in the form of a steam jet compressor or by throttling or water injection, and is introduced together with the mixed steam of the first mentioned vapour compressor into the first evaporator stage of the vaporiser section.

6. A vaporiser and method as claimed in claim 1, 3 or 4 without claim 2, wherein said vapour compressor is a mechanical compressor, which compressor is driven by a thermal power unit in which steam is expanded to the level of the steam leaving the comprssor and which is supplied together with the latter steam to the vaporiser section as process steam.

7. A vaporiser and method as claimed in any one of the preceding claims, wherein evaporated liquid vapour supplied to said heat transformer is partially conducted directly to an absorber in which is situated an unsaturated complex mixture which absorbs said evaporated liquid vapour with evolution of heat.

8. A vaporiser and method as claimed in claim 7, wherein the complex mixture, after having become saturated after absorption of said evaporated liquid vapour, is supplied by way of a pipe to an expulsion unit which is under a lower pressure than the pressure in the absorber and in which, with supply of heat, the complex mixture is regenerated by evaporation of the absorbed component, the regenerated complex mixture being returned by means of a pump into the absorber and the evaporated component being brought into heat exchange contact with the regenerated mixture before it is throttled to a lower pressure.

9. A vaporiser and method as claimed in claim 8, wherein the heat required for expelling said absorbed component has a temperature which is the same as or different from that of the evaporated liquid vapour introduced into the absorber, the vapours from one or more stages of said vaporiser section being used for this heating.

10. A vaporiser and method as claimed in any one of claims 1 to 6, wherein the proportion of vapours from said vaporiser stage provided for the heat transformer is supplied to an expulsion stage and an evaporator stage, readily boiling constituents of a complex mixture being evaporated by heat contact with the evaporated liquid vapour in the expulsion stage at low pressure, these constituents being thereafter liquefied in a condenser, conveyed by means of a pump into said evaporator stage which is under a higher pressure, are once again evaporated in said evaporator stage by heat contact with said evaporated liquid vapour and are thereafter absorbed by a complex mixture with a low content of readily boiling constituents in an absorption stage with evolution of heat; the expulsion stage and the absorption stage being so interconnected by way of pipes that, in one pipe, the complex mixture saturated after the absorption is throttled to the pressure of the expulsion unit and introduced into the latter and, by way of another pipe, the mixture from which said readily boiling constituents have been evaporated is extracted from the expulsion unit and returned by means of a pump into the absorber which is under the higher pressure, the saturated complex mixture and the mixture from which readily boiling constituents have been evaporated being brought at the higher pressure into heat exchange contact.

11. A vaporiser and method as claimed in any one of the preceding claims, wherein vaporous components leaving a or the explusion stage of the vaporiser are liquefied at a low temperature such as ambient temperature.

12. A vaporiser and method as claimed in any one of the preceding claims, wherein heat contained in vapour condensates of the vaporiser stages of the vaporiser section are additionally used for heating expulsion and/or vaporiser stages of the heat-return section.

13. A vaporiser and method as claimed in claim 7 or any one of claims 8 to 11 as appendant to claim 7, wherein the heat absorber is equipped on a heat-delivery side with a steam-generator system.

14. A vaporiser and method as claimed in any one of the preceding claims, wherein the heat-return section has vapour pipes leading thereto which are so connected to one another that, with the aid of regulating valves, the amounts of vapour intended for the heat transformer and for the vapour compressor can be adjusted as desired in dependence on or independently of one another.

15. A multi-stage vaporiser having a vaporiser section and a heat-return section, substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

16. A method of carrying out the process performed by the vaporiser as claimed in any one of the preceding claims, substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1981.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.