SINGLE STAGE CENTRIFUGAL COMPRESSOR REFRIGERATION SYSTEM

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This invention relates to an improved refrigeration system and particularly to means for improving the cooling capacity and efficiency of such a system employing a single-stage centrifugal compressor.

A single-stage centrifugal system enjoys notable advantages over comparable multi-stage compressor units in several respects. The single stage type is more compact for a given output of refrigeration tonnage, requires less maintenance, and is initially less expensive. The prior art has recognized that efficiency of a multi-stage compressor unit may be appreciably increased by introduction of flashed vapor into one or more of the higher compression stages. Interstage flash gas injection is practiced not only for the purpose of improving efficiency, but also affords more stable operation of the compressor under certain load conditions and extends considerably the capacity of the compressor unit.

To provide an efficient single-stage system, the present invention overcomes the problem of flash gas injection by injecting flash cooled fluid into the space normally defined by the compressor casing at either front or the rear shroud of the impeller. Such injection makes at least partial use of the disc friction in the compressor which is normally completely unused, in order to impart kinetic energy to the flashed gas and to reduce the relative velocity of such gas to the normal velocity of gas leaving the impeller so as to minimize gas mixing losses.

In accordance with one embodiment of the invention, the refrigeration system is provided including a single-stage centrifugal compressor for compressing refrigerant gas. The system includes a condenser and evaporator serially connected through an economizer in which at least a portion of the saturated liquid condensate from the condenser is flashed to subcool the remaining liquid. Means are further provided to introduce a stream of cooled flashed gas from the economizer to the single-stage compressor at a point downstream of the impeller inlet whereby the flashed gas will mix with compressed refrigerant. In effect, means is provided to introduce flashed gas into the compressor at a pressure level greater than the total inlet pressure of the compressor whereby the flashed gas will mix with and cool, hot compressed gas discharging from the impeller.

Thus, available output of the system in terms of usable tons of refrigeration is substantially increased with only a slight increase in load imposed upon the compressor. The overall result of this economical use of available energy is that the system efficiency realizes an increase up to about 10%.

It is therefore, an object of the invention to provide an improved closed refrigeration system circulating a vaporizable refrigerant, and utilizing single-stage refrigerant compression.

A further object is to provide a system of the type described having means for improving overall cycle efficiency by utilization of flashed gas refrigerant intermixed with compressed gas prior to discharge of the latter from the compressor.

A still further object is to improve operation characteristics of a single-stage refrigerant compressor by introducing flashed vapor refrigerant to the compressor for mixing with the compressed gas stream.

Still another object is to improve centrifugal compressor characteristics in a refrigeration system of the type described without affecting the compressor inlet capacity.

A further object of the invention is to provide a system having means to maintain a table impeller discharge temperature at front and rear labyrinth seals under extreme throttling conditions imposed by minimal compressor guide vane settings.

Another object is to provide the system of the type described having means to increase overall compressor output tonnage without increasing the impeller dimensions, or the compressor prime mover capacity.

Other objects not specifically delineated will become apparent to one skilled in the art from the following description of the invention made with reference to the accompanying figures.

In the drawings:

FIGURE 1 is a diagrammatic illustration of the refrigeration system utilizing flash gas cooling at the system single stage centrifugal compressor.

FIGURE 2 is a segmentary view in cross section of a single stage centrifugal compressor embodying the invention.

FIGURE 3 is a graphical illustration of the pressure enthalpy characteristics of a refrigeration system using flash gas injection.

FIGURE 4 is a segmentary view on an enlarged scale of an alternate embodiment of the discharge portion of the compressor shown in FIGURE 2.

FIGURE 5 is a segmentary view in cross section of an alternate embodiment of compressor construction.

FIGURE 6 is a segmentary view in cross section of another alternate embodiment of the compressor.

FIGURE 7 is a segmentary view in cross section of still another alternate embodiment of the compressor construction utilizing the features of the invention.

FIGURE 8 is a segmentary view of a modification of FIGURE 4 taken in a horizontal plane above the impeller.

Referring to FIGURE 1 of the drawings, the illustrated embodiment of the invention provides a closed refrigeration system circulating a vaporizable refrigerant in varying conditions of fluidity. The system includes a condenser and an evaporator serially connected through a flash chamber or economizer communicating therewith to receive at least a portion of saturated or sub-cooled refrigerant condensate from the condenser outlet. A single-stage centrifugal compressor having a suction inlet is communicated with the evaporator outlet receiving vaporous refrigerant. The compressor includes a rotatable impeller having an outlet adjacent the impeller tip directing compressed refrigerant at impeller tip velocity into a diffuser. Conduit means connected to the vapor holding portion of the system flash chamber directs a stream of vaporized refrigerant at flash pressure approximately equal to condenser pressure, to a point upstream of the compressor discharge and downstream of the suction inlet. The introduced flashed gas is injected into the hot compressed gas stream at a pressure intermediate the compressor inlet and the compressor discharge pressures.

Referring again to FIGURE 1, there is illustrated a closed refrigeration system of the type generally familiar to the art which includes a condenser 10 having an outer shell surrounding a coil or tube 11 positioned within the shell and connected to a supply of circulating condenser water which may originate at a sink or other source or may be circulated through an external unit such as a cooling tower not presently shown. Condenser 10, following standard practice, includes a receiver or hot well
comprising a chamber into which under normal operating conditions, saturated liquid refrigerant at substantially compressor discharge pressure is received after being condensed by contact with cooling coil. A float control or similar type valve in chamber meters a stream of liquid through conduit to inlet of flash chamber in response to the level of contained liquid in the chamber.

Flash chamber receives and holds saturated liquid at a pressure slightly less than condenser header pressure thus flashing at least a portion of the liquid. A first outlet at the upper or vapor holding side of flash chamber is connected to conduit 20 conducting vaporized refrigerant to the compressor as will be hereinafter described in greater detail.

A second conduit connected to flash chamber receives refrigerant in liquid phase and in a saturated condition. An expansion valve disposed upstream of conduit 21 controls flow to inlet of evaporator.

Evaporator comprises a shell having an inlet and is adapted to receive and hold a pool of liquid refrigerant condensate. A coil in the shell lower side circulates liquid from an external source giving up heat to the condensate. As is normally provided for in refrigeration apparatus of this type, a mix or liquid eliminator is positioned above the evaporator shell and serves to pass the surface of boiling refrigerant to permit only gas to enter outlet 27. Conduit 28 connected to outlet 27 leads vaporous refrigerant to the compressor suction for recompression and recirculation in the system.

Compressor as shown generally in FIGURE 1 and in greater detail in FIGURE 2, includes a casing formed with an inlet or suction into which is incorporated an adjustable vaned or other type gas flow regulating means for adjusting the rate of refrigerant gas fed to the compressor. The centrifugal compressor includes an impeller rotatably journaled within casing 32 defining a single-stage in which refrigerant gas is compressed. Impeller 34 including hub 35, carries a rearwardly depending shaft mounted in bearing and driven by a motor or other prime mover either directly or through appropriate gearing means for adjusting the speed of the compressor relative to drive motor speed.

Impeller 34 is supported with its center adjacent casing and may be of the open or closed type, either of which embodiment is adapted to the practice of the invention although the closed or shrouded form is preferred. The impeller periphery or tip portion terminates at a constricted passage formed at the casing outer edge defining a narrow diffuser having annular openings to receive high velocity compressed refrigerant leaving the impeller tip.

A circular seal 37 carried on the casing 32 inner wall engages the impeller forward peripheral surface to form a gas tight joint. A similar arrangement at hub 35 defines a rear seal 37.

Following standard practice, refrigerant gas within the compressor impeller passages is provided with a predetermined energy level dependent on impeller design and upon the speed of rotation. The total energy imparted to the gas is acquired in two stages, that is, compression energies and kinetic energy in the form of rotational velocity. In diffuser, high velocity compressed gas is expanded from an intermediate pressure at the impeller tip to a low velocity maximum pressure at the diffuser discharge chamber. Chamber 41 connected to outlet 42 conduit 43 for leading hot vaporous compressed refrigerant to the inlet of condenser 10. Compressor casing 32 is formed with a plurality of gas inlet means. At least one of said inlet means is adapted to receive flashed refrigerant gas at a pressure slightly greater than impeller discharge pressure. Thus, conduit 20 connected with flash chamber 18 is connected to opening 46 in casing 32 carrying flashed refrigerant gas for injection into the stream of hot refrigerant gas discharging from the impeller.

It is found that to effectively utilize cool flashed gas at the single stage compressor, the cooling stream is introduced not through the compressor inlet but rather at a point downstream of the suction inlet and prior to reaching the discharge. Thus, although flashed gas is introduced at an optimal point to be defined hereinafter more precisely, introduction may be suitably affected at any one of several physical locations within the compressor casing so as to properly incorporate the intermix cooled, flashed refrigerant into the rotating stream of hot compressed refrigerant gas.

As shown in FIGURE 4, an alternate embodiment of the compressor generally illustrated in FIGURE 2, includes a manifold 61 formed on the casing adjacent to diffuser passage 63. A discharge chamber 64 receives a stream of mixed compressed refrigerant gas leaving impeller 66 at high rotational velocity. An inlet 68, manifold 61 is communicated through line to the refrigerant system flash chamber 18, conducting flash refrigerant gas to the manifold. A plurality of openings 67 communicate manifold 61 with diffuser passage 63 to introduce streams of the flashed gas into the high velocity flow of hot compressed refrigerant flowing in the diffuser passages.

The high velocity of gas as it leaves the impeller tip and sweeps across the openings of passages 67, will aspirate flashed gas therefrom, thus providing for better mixing of the two streams prior to entering chamber 64.

As shown in FIGURE 8, passages 67' in the present embodiment comprise a plurality of equispaced passages positioned adjacent one to the other and passing flashed gas into diffuser 63' for mixing with hot compressed gas. The passages are so biased relative the spiralling stream of hot compressed gas to effect an optimum rate of flashed gas introduction. Passages 67' may consist of peripherally spaced bores formed into the wall of casing 62'. Alternately, they may be provided in the form of an insert or inserts disposed in the casing wall communicating chamber 61 with diffuser passage 63.

As seen in FIGURE 8, the angle of injection for flashed gas is about 30° to the plane of said diffuser passage and about 20° from the horizontal. These figures however are not intended to constitute limitations since the optimum angle of gas injection is a function of gas velocity in diffuser passage 63.

The closed refrigeration system described is normally used in installations which circulate a vaporizable refrigerant medium of the Freon type commonly designated as R-11, R-12, R-22 or mixtures thereof. Fluid circulation rate through the system is variable in response to loading conditions imposed by cooled fluid circulating through evaporator coil 26 and, or conditions in other parts of the system.

To define the instant cycle diagrammatically, reference is made to FIGURE 3 depicting a Mollier chart appropriately lettered to form the refrigeration cycle shown and to illustrate the improved efficiency and performance realized through flashed gas injection. Thus, at point A on the saturation line of the chart, refrigerant in the cycle is introduced from the evaporator discharge to the compressor suction at a predetermined low pressure depending on the characteristics of the particular refrigerant.

Polytropic compression of the gas is carried out along line A-B as the refrigerant is driven at high speed toward the impeller periphery.

Normally, without interstage injection, polytropic compression would continue along an uninterrupted line commencing at point A and terminating at point B. However, as presently shown, at point B in the compression cycle line intermediate the minimum and maximum refrigerant pressures, flashed gas is introduced at K. Introduction of this cooled gas to the compressor hot gas flow has the effect of displacing the compression line to
C. Since only a limited amount of refrigerant is introduced, normal polytropic compression of the gas mixture will thereafter continue from point C to point D.

Between points D and F and at substantially constant pressure P3, hot compressed refrigerant gas is condensed to saturated or slightly sub-cooled condition. Expansion of liquid to gaseous state through an expansion valve proceeds along line F-G to pressure P2.

Flushed cooled vapor at P2 is directed as mentioned above, to the compressor for mixing with hot compressed gas at point C. The remaining unflushed condensate due to the partial flushing is cooled to point P2. This liquid is then expanded from H through J by way of second valve, into the evaporator for evaporation and absorption of heat to point A. Thereafter, the cycle recommences by compression of vaporous gas passed from the evaporator to the compressor suction.

Following the practice of the invention, flushed cool refrigerant gas from chamber 18 is introduced to compressor casing 32 at any of several positions to effect the desired mixing of flashed gas with hot compressed refrigerant.

As shown in FIGURE 5 which illustrates an alternate embodiment of the compressor assembly shown in FIGURES 1 and 2, impeller 48 at its forward or suction side is provided with an opening or a plurality of openings 47. These openings communicate with interwall chamber 48 having an inlet 49 which may be either manifolded or connected directly by way of line 20 to flash chamber 18. Openings 47 in the impeller, are positioned at a point intermediate the compressor suction inlet and upstream of the impeller peripheral edge such that the flashed gas is carried from chamber 48 by virtue of impeller disc friction, and caused to mix with the rotating compressed gas stream prior to discharge from the impeller tip.

Referring to FIGURE 6, another embodiment of the compressor impeller shown in FIGURE 2 is characterized by a plurality of circularly spaced vanes 51 carried on the impeller forward face or adjacent the impeller tip in such manner as to project into chamber 52. Thus, flashed gas introduced to interwall chamber 53 by way of opening 52' from flash chamber 18, will be urged into a swirling circumferential direction by the combined effects of impeller disc friction and vanes 51. The gas will then be urged through the opening defined by vanes 51, into the main stream of compressed refrigerant within the impeller. While vanes 51 provide a forced spiral motion to introduced flashed gas, these vanes are not entirely necessary for achieving the required introduction in mixing of the two gas streams. Others do, however, impart a positive circulatory motion to the gas to assure improved mixing of the two streams.

As shown in FIGURE 7, intrastage introduction of gas is not limited to injection into the compressor casing at the forward side. Flashed cooling gas may also be directed into the rear face of the casing and thus be swept into the impeller 59 main gas stream in a manner similar to the manner previously described. In this instance, openings 53 are formed the under the rear side of impeller 59 and are connected through a manifold 54 to conduit 19 leading from the flash chamber 18. Thereafter, the introduced gas is induced toward the impeller tip and aspirated into the main gas stream in the manner described.

It will be appreciated by those familiar with the art that the present invention providing improved cycle efficiency, constitutes a preferred embodiment of the apparatus and the arrangement thereof. Certain modifications and changes may, however, be made in the invention as a whole without departing from the spirit and scope of the invention.

What is claimed is:

1. In a closed refrigeration system circulating a vaporizable refrigerant and including a condenser forming a high pressure stage and an evaporator in the system forming a low pressure stage:
   (a) a single stage centrifugal compressor having a suction inlet connected to receive refrigerant gas from the low pressure stage, and having an outlet discharging hot compressed refrigerant gas to the high pressure stage;
   (b) receiver means interconnecting said high pressure stage and low pressure stage respectively and holding refrigerant condensate in liquid and vapor phase at a pressure less than condenser pressure and higher than evaporator pressure to flash at least a portion of the so held refrigerant into the vapor phase, and
   (c) conduit means communicating the vapor holding portion of said receiver means with the compressor at a point past the suction inlet of the compressor for mixing flashed gas which is at a pressure higher than the suction inlet pressure with hot compressed gas prior to discharge thereof from the compressor outlet.

2. In a system substantially as defined in claim 1 wherein said receiver means includes:
   (a) a flash chamber having an inlet connected to the condenser forming the high pressure stage and receiving liquid condensate to flash at least a portion of the so held refrigerant into the vapor phase.

3. In a refrigeration system including a condenser forming a high pressure stage, a receiver connected downstream of the condenser holding flashed refrigerant and gas at substantially condenser pressure, and a single stage compressor in said system circulating hot compressed refrigerant gas, said compressor including:
   (a) a casing,
   (b) an impeller having a peripheral tip and being rotatively journaled in the casing forming therewith a single stage compression chamber, and
   (c) means in the casing forming a suction inlet to the compression chamber and connected to receive a stream of vaporized refrigerant gas,

4. In a refrigeration system substantially as defined in claim 3 wherein said means forming a second inlet in the casing includes a plurality of inlets peripherally disposed about the casing.

5. In a refrigeration system substantially as defined in claim 4 wherein said casing includes a manifold formed thereon mutually connecting said plurality of inlets, and said conduit means being communicated with the manifold.

6. In a refrigeration system substantially as defined in claim 3 wherein said means forming a second inlet in the casing terminates at a point downstream of the impeller tip.

7. In a refrigeration system substantially as defined in claim 3 wherein said discharge means in the casing includes a constricted diffuser means disposed adjacent the impeller tip receiving a high velocity stream of gas therefrom.

8. In a refrigeration system substantially as defined in claim 3 wherein said means forming a second inlet includes a plurality of passage means in the casing terminating at said diffuser passage.

9. In a refrigeration system substantially as defined in claim 4 wherein:
   (a) said casing includes a manifold formed thereon mutually connecting said plurality of inlets and said conduit means, and
(b) said plurality of inlets being so biased relative the stream of hot compressed gas as to effect an optimum rate of introduction of flashed gas from the receiver.

10. In a refrigeration system as defined in claim 3 wherein:
(a) the means forming a second inlet in said casing include a manifold chamber formed thereon, and
(b) a plurality of openings in the impeller positioned at a point intermediate the compressor suction inlet and upstream of the impeller peripheral edge communicate the manifold with the discharge means in the casing so that the flashed gas is carried from the manifold chamber by virtue of impeller disc friction, and caused to mix with the rotating compressed gas stream prior to discharge from the impeller tip.

11. In a refrigeration system as defined in claim 10 wherein the impeller carries a plurality of circularly spaced vanes which project into the manifold chamber and which serve to urge the flashed gas into a swirling circulatory direction and to draw said gas into the main stream of compressed refrigerant within the impeller thereby assuring improved mixing of the two streams.

12. In a refrigeration system as defined in claim 10 wherein the flashed gas is directed into the rear of the casing.

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