

SCROLL APPARATUS WITH ENHANCED LUBRICANT FLOW

The invention relates to the lubrication of co-rotational scroll apparatus and particularly, but not exclusively, to the lubrication of the scroll wraps of such apparatus.

Scroll apparatus for fluid compression or expansion are typically comprised of two upstanding interfitting involute spirodal wraps which are generated about respective axes. Each respective involute wrap is mounted upon an end plate and has a tip disposed in contact or near-contact with the end plate of the other respective scroll wrap. Each scroll wrap further has flank surfaces which adjoin in moving line contact, or near contact, the flank surfaces of the other respective scroll wrap to form a plurality of moving chambers. Depending upon the relative orbital motion of the scroll wraps, the chambers move from the radial exterior end of the scroll wraps to the radially interior ends of the scroll wraps for fluid compression, or from the radially interior end of the respective scroll wraps for fluid expansion. The scroll wraps, to accomplish the formation of the chambers, are put in relative orbital motion by a drive mechanism which constrains the scrolls to non-rotational relative motion. The general principles of scroll wrap generation and operation are discussed in numerous patents, such as US Patent Number 801, 182.

Numerous attempts have been made to develop co-rotational scroll apparatus. Such apparatus provides for concurrent rotary motion of both scroll wraps on parallel, offset axis to generate the requisite orbital motion between the respective scroll wrap elements. However, most commercially successful scroll apparatus to date have been of the fixed

scroll-orbiting scroll type due to various difficulties in achieving success with co-rotating scroll apparatus.

Typically, a number of rotary bearings are required in a co-rotational scroll apparatus, which decreases the reliability and efficiency of the machine. Furthermore, the typical co-rotating scroll apparatus have required a thrust bearing acting upon each of the scroll end plates to prevent axial scroll separation, thus substantially increasing the power requirements of the machine as well as substantially reducing the reliability of the machine.

In addition to the energy consumed by the additional bearing surfaces typically found, fluid around and in the vicinity of the scrolls is "fanned" by the scroll members. After the scrolls have been rotating for a period of time, the fluid adjacent the scrolls develops a swirling or centrifugal flow field around the periphery of the scrolls due to the motion of the scroll members. This presents a substantial difficulty when the scroll members are contained in a shell or enclosure, with respect to obtaining and controlling adequate lubricant flow through the scroll wraps of a co-rotational scroll apparatus.

In many applications such as refrigeration and air conditioning, the scroll apparatus is employed as a gas compressor in a closed circuit system. Lubrication of the compressor in such systems is typically accomplished by providing a lubricant which is miscible in the gas to be compressed, and circulating all or a portion of this lubricant in the closed system. The effect of the centrifugal flow field is to precipitate this miscible lubricant out of the gas, leaving effectively no lubricant available to flow through the scroll wraps of the scroll apparatus

and filling the container in which the scrolls rotate with lubricant. This lubricant accumulating in the container also tends to be swirled by the scrolls, requiring additional energy input to the scrolls.

5 In certain co-rotational scroll apparatus, lubricant is also provided to the bearings supporting the scroll elements. This lubricant also contributes to the lubricant accumulation in the container as it flows from the bearings after having lubricated them.

10 An object of the invention is to provide a co-rotational scroll apparatus in which a controlled, effective and adequate flow of lubricant is provided.

Accordingly the invention provides a scroll apparatus comprising:

15 a first scroll member having an end plate and a scroll wrap disposed on said end plate;

a second scroll member having an end plate and a scroll wrap disposed thereon, said scroll wraps being cooperably arranged for forming, in use of the apparatus, an alternately open and closed first chamber therebetween, said second scroll member end plate defining a lubricant passage having an outlet in flow communication with said first chamber;

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tube means in flow communication with said lubricant passage and arranged to pick-up lubricant, in said use of the apparatus, for delivery to said lubricant passage; and

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means for rotating said first and second scroll members.

30 The invention also includes a scroll apparatus comprising:

a shell defining a suction pressure portion and a sump;

a first scroll member disposed in said suction pressure portion, said first scroll member having an

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end plate having a shaft and an oppositely directed scroll wrap disposed thereon;

5 a second scroll member disposed in said suction pressure portion, said second scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being in interleaving engagement for cooperably forming, in use of the apparatus, an alternately open and closed first chamber therebetween, said second scroll member
10 end plate defining a lubricant passage having an outlet disposed adjacent an outer end of the scroll wrap of said second scroll member for flow communication with said first chamber;

15 a lubricant pickup tube affixed to said second scroll member for picking up lubricant from said sump and delivering it to said lubricant passage:

bearing means for rotatably supporting said first scroll member and said second scroll member; and

20 means for concurrently rotating said first and second scroll members.

The invention also includes a scroll compressor apparatus comprising:

25 a hermetic shell defining a suction pressure portion, a discharge pressure portion and a sump in said suction pressure portion;

30 a first scroll member disposed in said suction pressure portion, said first scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said first scroll member comprising a lubricant passage having an outlet defined in said end plate;

35 a second scroll member disposed in said suction pressure portion, said second scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being

in interleaving engagement for cooperably forming, in use of the apparatus, an alternately open and closed first chamber, said chamber being in flow communication with said outlet;

5 pickup tube means cooperating with said lubricant passage to define a flow path between said sump and said outlet;

respective bearing means for rotatably supporting said first and second scroll members;

10 means for lubricating said first and second scroll member bearing means; and

a motor driveably connected to said shaft of the first scroll member for rotating said first scroll member; and

15 means for concurrently rotating said second scroll member with said first scroll member.

The invention further includes a refrigeration system for circulating refrigerant in closed loop connection, the system comprising:

20 a condenser for condensing refrigerant to liquid form;

an expansion device for receiving liquid refrigerant from said condenser and expanding said refrigerant;

25 an evaporator for receiving refrigerant from said expansion device and evaporating the refrigerant to vapour form; and

a compressor for receiving refrigerant from the evaporator and compressing and sending the refrigerant to the condenser, said compressor comprising:

30 a hermetic shell defining a suction pressure portion, a discharge pressure portion and a sump in said suction pressure portion;

35 a first scroll member disposed in said suction pressure portion, said first scroll

member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said first scroll member defining a lubricant passage;

5 a second scroll member disposed in said suction pressure portion, said second scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being in interleaving
10 engagement for forming, in use of the compressor, an alternately open and closed first chamber therebetween, said chamber being in flow communication with said lubricant passage defined in said first scroll member;

15 pickup tube means in flow communication with said lubricant passage and said sump;

bearing means for rotatably supporting said first scroll member;

20 bearing means for rotatably supporting said second scroll member;

means for lubricating said second scroll member bearing means; and

25 a motor driveably connected to said first scroll member shaft for rotating said second scroll member concurrently with said first scroll member.

30 The invention also includes a co-rotational scroll-type fluid apparatus wherein provision is made for lubricant flow through the length of the scroll wraps by virtue of there being provided tube means which in operation of the apparatus picks-up lubricant for delivery to a lubricant outlet arranged for introducing said lubricant into the region where the scroll wraps in said operation cooperate to define an
35 initial fluid-transfer chamber.

In order that the invention may be well understood, some embodiments thereof, which are given by way of example only, will now be described with reference to the accompanying drawings, in which:

5 Figure 1 is a cross-sectional view of a co-rotational scroll apparatus;

 Figure 2 is a schematic representation of a closed circuit system such as a refrigeration or air conditioning system in which the co-rotational scroll apparatus can be used;

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 Figure 3 is an enlargement of a portion of Figure 1;

 Figure 4 is a partial cross-sectional view of a first alternative embodiment of the co-rotational scroll apparatus;

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 Figure 5 is a partial cross-sectional view of a co-rotational scroll apparatus showing features which can be incorporated with the embodiments of Figures 6 and 8;

20 Figure 6 is a partial cross-sectional view of a second alternative embodiment of the co-rotational scroll apparatus;

 Figure 6A shows a lubricant pickup tube;

 Figure 6B shows another lubricant pickup tube;

25 Figure 6C shows yet another lubricant pickup tube;

 Figure 7 is a partial cross-sectional view of a co-rotational scroll apparatus showing features which can be incorporated with the embodiments of Figures 6 and 8;

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 Figure 8 is a partial cross-sectional view of a third alternative embodiment of the co-rotational scroll apparatus;

35 Figure 9 is a partial cross-sectional view of a fourth alternative embodiment of the co-rotational

scroll apparatus;

Figure 10 shows a cross-sectional view taken along section line 10-10 of Figure 5 with the preferred disposition of the lubricant passage outlets highlighted thereon;

Figure 11 is a cross-sectional view taken along section line 11-11 of Figure 4 with the preferred disposition of the lubricant passage outlets highlighted thereon; and

Figure 12 is an enlarged partial cross-sectional view of a fifth alternative embodiment of the co-rotational scroll apparatus.

A scroll-type fluid transfer apparatus having co-rotational scroll members is shown in Figure 1 as a scroll compressor assembly 20. In the described embodiments, the scroll apparatus is a hermetic scroll compressor assembly and is interchangeably referred to as a scroll apparatus or as a compressor assembly 20. It will, however, be readily apparent to those skilled in the art that the scroll apparatus 20 may be used as a fluid pump or expander. Additionally, it will be understood that the scroll apparatus need not be of the hermetic type.

Referring to Figures 1 and 3 the compressor assembly 20 includes a hermetic shell 22 having an upper shell portion 24, a lower shell portion 26 and a central shell portion extending between the upper and lower portions. The central shell portion comprises a central frame portion 28 affixed within an exterior shell 27. The exterior shell 27 is a generally cylindrical body, while the frame portion 28 is defined by a generally cylindrical or annular exterior portion 30 and a central portion 32 disposed across one end thereof. The annular exterior portion 30 is sized to sealingly fit within the exterior shell

27 so that it may be mated thereto by a press fit, by welding, or by other suitable means.

Integral with the frame portion 28 is a generally cylindrical upper bearing housing 34, which is substantially coaxial with the axis of the annular exterior portion 30. A drive shaft aperture 36 extends axially through the centre of the upper bearing housing 34, and an upper main bearing 38 is disposed radially within the drive shaft receiving aperture 36. Preferably, the upper main bearing 38 is a sleeve bearing made, for example, of sintered bronze or similar material. The upper main bearing 38 may alternatively be of the roller or ball bearing type.

A motor 40 is disposed within the upper and central portions of the hermetic shell 22. The motor 40 is preferably a single phase or three phase electric motor comprised of a stator 42 which is circumferentially disposed about a rotor 44, with an annular space therebetween permitting free rotation of the rotor 44 within the stator 42 as well as the flow of lubricant or refrigerant fluid. The stator 42 may be affixed within the exterior shell 27 by a press fit therebetween, by a plurality of bolts or screws (not shown), by weldments between appropriate surfaces on the stator 42 and the exterior shell 27 (not shown), or by other means. It will be readily apparent to those skilled in the art that alternative types of motors 40 and means of mounting the motor 40, and alternative types of drive means, would be equally suitable for application in the compressor assembly.

A discharge aperture 50 is shown in the upper shell portion 24 for discharging high pressure fluid from the scroll apparatus 20 and a shell suction aperture 52 is shown disposed in the lower shell portion 26 for receiving low pressure fluid into the

scroll apparatus 20. This permits connection of the scroll apparatus 20 to a suitable fluid system. Preferably, the scroll compressor apparatus 20 would be connected to a refrigeration or air conditioning system. Such a system is shown generally in schematic representation in Figure 2. The representative system includes a discharge line 54 connected between the shell discharge aperture 50 and a condenser 60 for expelling heat from the refrigeration system and condensing the refrigerant. A line 62 connects the condenser to an expansion device 64. The expansion device may be a thermally actuated or an electrically actuated valve controlled by a suitable controller (not shown), or may be one or more capillary tubes. Another line 66 connects the expansion device 64 to an evaporator 68 for transferring expanded refrigerant from the expansion device 64 to the evaporator 68 for acceptance of heat. Finally, a refrigeration system suction line 70 transfers the evaporated refrigerant from the evaporator 68 to the compressor assembly 20, wherein the refrigerant is compressed and returned to the refrigeration system.

It is believed that the general principles of refrigeration systems capable of using such a compressor system 20 are well understood in the art, and that detailed explanation of the devices and mechanisms suitable for constructing such a refrigeration system need not be discussed in detail herein. It is believed that it will also be apparent to those skilled in the art that such a refrigeration or air conditioning system may include multiple units of the compressor assembly 20 in parallel or series connections, as well as multiple condensers or evaporators and other components, hence such embodiments of refrigeration systems need not be

discussed here in detail.

5 The scroll apparatus 20 further comprises a drive
scroll member 76 arbitrarily designated the first
scroll member, and an idler scroll member 78,
10 arbitrarily designed the second scroll member. The
first scroll member 76 includes an upstanding involute
scroll wrap 80 which is integral with a generally
planar drive scroll end plate 82. The drive scroll
end plate 82 includes a generally centrally disposed
15 scroll member drive shaft 84 extending oppositely from
the upstanding involute scroll wrap 80. A discharge
gallery 86 is in flow communication with a discharge
aperture 88 defined by a generally central bore
through the drive scroll end plate 82. The drive
20 shaft 84 includes a first, relatively larger diameter
bearing portion 90 extending axially through the upper
main bearing 38 (which constitutes a means for
rotatably supporting the first scroll member) for a
free rotational fit therein, and a second relatively
25 smaller diameter rotor portion 92 which extends
axially through the rotor 44 and is affixed thereto.
The rotor 44 may be affixed to the rotor portion 92 by
such means as a power transmitting key in juxtaposed
keyways, a press fit therebetween, or other suitable
means.

30 The second or idler scroll member 78 includes a
scroll wrap 100 which is disposed in interfitting and
interleaving engagement with the scroll wrap 80 of the
first scroll member. The second scroll member 78 also
includes a substantially planar second scroll member,
or idler, end plate 102. The scroll wrap 100 is
generally an upstanding involute extending from the
idler end plate 102. A second scroll member shaft, or
idler shaft stub, 104 extends from the idler end plate
35 102 oppositely from the scroll wrap 100.

It is to be understood that the designation of the idler scroll member 78 as the second scroll member and the drive scroll member 76 as the first scroll member is arbitrary and may be made interchangeably without affecting the character of the invention.

An annular bearing 110, which may be a sleeve bearing made of sintered bronze material, for example, or may be of the roller or ball type, is disposed within an annular wall defining a lower bearing housing 112. The lower bearing housing 112 is integral with the lower hermetic shell portion 26 and together with the bearing 110 provides rotational support for the second scroll member 78.

The first scroll member end plate 82 also includes two extension members 120 extending from the end plate 82 parallel to the drive scroll wrap 80. The extension members 120 are disposed at radially opposed positions near the outer edge of the first scroll member end plate 82 and are of greater length than the height of the involute scroll wraps 80 and 100, respectively, plus the thickness of end plate 102. The extension members 120 are affixed to an annular compression plate 150. The compression plate 150 is generally cup shaped, having an annular generally planar circumferential portion 152 about the radial outward edge thereof. The radially outward portion 152 includes a recess 154 for each extension member 120. The extension member 120 may be affixed in the recess 154 by such means as threaded fastener, welding or a press fit. A depressed planar central portion 156 is parallel to and downwardly spaced a distance from the circumferential portion 152. This central portion 156 includes a second, slightly more downwardly spaced area describing an annular retaining shoulder 158 and a biasing surface 160. A central

through-aperture 162 is described by a bore through the axial centre of the central portion 156. The central aperture 162 is of substantially greater diameter than the lower bearing housing 112 so that there is sufficient clearance between the compression plate 150 and the lower bearing housing 112 to permit the compression plate 150 to rotate freely about the lower bearing housing 112.

A spring 170 is disposed between the biasing surface 160 and the second scroll end plate 102. The compression spring 170 serves to bias the respective scroll end plates 82 and 102 toward each other by exerting a force upon the second scroll member end plate 102 and an opposite force upon the first scroll member end plate 82 through the compression plate 150 and extension members 120. In this embodiment, the spring 170 is retained within an annular channel 114 formed in the second scroll member end plate 102. This permits the spring 170 to act as a torque transmitting element. In this embodiment, the extension members 120, the compression plate 150 and the spring 170 together comprise a drive means for causing concurrent rotation of the first scroll member 76 and second scroll member 78 and a means for biasing the scroll members towards one another.

An annular thrust bearing 176 is disposed on an upper shoulder 178 of the lower bearing housing 112 for accepting the weight of the first and second scroll members 76 and 78 as well as the drive shaft 90 and the rotor 44. It will be appreciated by those skilled in the art that although the scroll apparatus 20 is shown having its axis generally vertically aligned, that the apparatus 20 will function equally well in non-vertical orientations. It is desirable, however, to maintain a vertical or near vertical

position (for example, within 45 degrees of vertical) so that the mass of the rotor 44 and the scrolls 76 and 78 will bias the second scroll member 78 against the thrust bearing 176.

5 A reservoir 180 for containing lubricant is provided in the central portion 32 of the frame portion 28. The lubricant therein is provided to the upper main bearing 38 through an upper bearing lubricant bore 182 in the upper bearing housing 34.
10 A bore 184 provides flow communication through the central portion 32 of frame portion 28 allowing lubricant from the reservoir 180 to pass into a lubricant feed tube 186 and thence through a passage 188 in the lower bearing housing 112 for lubricating
15 the lower bearing 110. The upper main bearing 38 and the lower bearing 110 are sized with respect to their housing 34 and 112 so that the flow of lubricant discharged into the suction pressure portion of the hermetic shell defined by the lower portion 26 and
20 frame portion 28 is controlled in quantity.

 A radially extending lubricant passage 200 is defined in the second scroll member end plate 102 and has an outlet 202 which permits fluid flow from the lubricant passage 200 to a first chamber 204 formed by
25 the outer ends 206 and 208 of the scroll wraps 80 and 100 respectively. It will be noted that while the first chamber 204 in a compression device is a compression chamber, the first chamber 204 is in fact also a suction chamber since it is open to suction
30 pressure during at least a portion of the rotation of the scroll apparatus, so that the term is used interchangeably therein.

 Since the pressure of the lubricant in the lubricant passage 200 is at, or slightly above, the
35 suction pressure, it will be appreciated that

lubricant flow into the first chamber can occur only when the pressure in the first chamber is at or only slightly above the suction pressure. Therefore, the lubricant passage outlet 202 must be defined in the first member scroll end plate 82 at a location adjacent the outer tips 206 or 208 of the scroll wraps 80 or 100 to permit lubricant to flow into the first chamber 204 when the chamber is open to the suction pressure portion of the hermetic shell which is defined by the lower shell 26 and the frame portion 28. It will be apparent to those skilled in the art that because of the minimal pressure difference between the lubricant flowing into the lubricant passage 200 and the pressure of the fluid accepted into the first chamber when the first chamber is open that the lubricant passage outlet 202 must be disposed to permit lubricant flow into the first chamber 204 before there has been any substantial compression therein, as such compression could result in a pressure exceeding the pressure of the lubricant and preventing lubricant flow. The preferable disposition of locations of the lubricant passage outlet 202 is more clearly shown in Figures 10 and 11, discussed hereinafter.

A lubricant passage inlet 216 is provided in said second scroll member at the radially inner end of the lubricant passage 200 for receiving lubricant from a means for delivering lubricant from the bearing 110 to the lubricant passage, the means for delivering comprising a collection chamber 217 disposed between the end plate 102 and the thrust bearing 176. Pickup tube means comprising a lubricant pickup tube 220 having an inlet aperture 232 is provided at a location slightly radially outward of the inlet 216. The tube 220 extends through the through-aperture 162 of the

compression plate 150 such that the inlet aperture 232 is disposed in a sump 222 defined in the suction pressure portion of the scroll apparatus 20. The lubricant pickup tube 220 is in flow communication with the lubricant passage 200 and in use of the scroll apparatus picks-up lubricant in the sump for delivery to the lubricant passage.

A plug 218 is provided in the outer radial end of the lubricant passage 200. This plug 218 is necessitated by the fact that the lubricant passage 200 as shown is drilled into the second scroll member end plate 102. Alternative means of constructing the second scroll member end plate 102 might render the plug 218 unnecessary, as the passage 200 would be fully contained within the end plate 102. Those skilled in the art will recognise that alternative means of forming the passage 200 or replacing the plug 218 are available.

It will also be appreciated by those skilled in the art that while two radially opposed lubricant passages 200 are shown in the second scroll member end plate 102, it would be possible to provide three, four or more lubricant passages 200, and such passages 200 need not be either radially opposed or equally radially or angularly spaced. Furthermore, it would also be possible to provide a single lubricant passage 200, which in some applications may be desirable for improving the dynamic balance of the scroll member in which the passage 200 is provided. Therefore, the provision of two identical means of providing the lubricant flow are shown in each embodiment and figure of the specification for descriptive purposes only.

Figures 10 and 11 contain cross-section views of the scroll members 76 and 78, taken from Figures 5 and 4, respectively, for convenience. In Figures 10 and

11, outlined areas D1 and D2 represent exemplary portions of the scroll end plate in which the lubricant passage outlets 202 may preferably be disposed. In Figure 10, D1 represents the area adjacent the end 206 of the scroll wrap 80, while D2 represents the area adjacent the end 208 of the opposing scroll wrap 100. In Figure 11, D1 represents the area adjacent the end 208 of the scroll wrap 100, while D2 represents the area adjacent the end 206 of the opposing scroll wrap 80. The areas D1 and D2 should be considered exemplary rather than limiting, as variations in scroll profiles and other similar factors and the desirability of using a greater or lesser number of lubricant passages 200 or outlets 202 may alter the actual disposition thereof.

It will be appreciated that the outlet 202 is preferably disposed close to the scroll wrap in each case to maximise lubricant flow prior to closure of the first chamber 204. Likewise, the outlet 202 will preferably be disposed as closely as possible to the end of the scroll wrap 80 or 100 so as to maximise lubricant flow. As the outlet 202 is disposed at a point increasingly removed circumferentially from the scroll wrap end 206 and 208 or removed radially from the scroll wrap 80 and 100, the length of time during which the outlet 202 will be exposed to the pressurised fluid within the first chamber 204 during a portion of each compression cycle increases. This pressure could overcome the relatively low pressure in the lubricant passage 200, causing a flow reversal and undesirable flow of the pressurised fluid from the first chamber 204 into the lubricant passage 200. It is therefore generally desirable to reduce the length of time during which the outlet 202 will be exposed to the pressurised fluid within the first chamber 204 in

order to prevent the potential flow reversal.

Alternative embodiments of the scroll apparatus 20 will now be described with particular reference to Figures 4, 6, 8, 9 and 12. In Figures 4, 6, 8 and 12, the scroll apparatus 20 is shown without an interconnecting drive means between the first and second scroll members. Those skilled in the art will recognise that alternative means of causing concurrent rotation between the scroll members are readily available. These include the use of flexible members affixed to the respective scroll end plates or the use of the extension members and drive keys to operate a ring or Oldham coupling between the respective scroll end plates. As there are various alternative drive means for rendering operational the co-rotational scroll apparatus 20, the drive means is omitted for the sake of clarity in these figures.

It should be noted that when the same item or feature appears in a figure illustrating an alternative embodiment of the scroll apparatus or features which may be incorporated in an alternative embodiment, it is labelled with the same reference numeral, followed by a numeric suffix. The numeric designation of an alternative embodiment does not correspond to its preference.

As shown in Figures 4, 8 and 12, a baffle 233-1, 233-5 and 233-7 may be provided to control the lubricant within the respective sump 222 to minimise undesirable foaming or splashing due to the movement of the respective pickup tubes 220 therein. The respective baffle 233 also serves as means for reducing the rotational velocity of the lubricant induced by the centrifugal flow field. This in turn increases the relative velocity of the respective pickup tube inlet 232 with respect to the lubricant

and therefore increases the rate of lubricant flow into the pickup tube inlet 232. Preferably the baffle 233 is in the form of an annular disk, extending about the lower bearing housing 112, and is spaced from the lower hermetic portion 26 to form a quiescent pool of lubricant swept by the pickup tubes 220. Means for supporting the baffle at the selected spacing include formed or welded tabs extending from the baffle or supports extending from the lower shell portion 26. It is believed that other such means will be obvious to those skilled in the art.

It will be appreciated that apart from the baffle 233-1, the first alternative embodiment of the scroll apparatus shown in Figure 4 corresponds to the embodiment shown in Figures 1 and 3.

Figures 5 and 7 each show features which may be incorporated with the embodiments of the scroll apparatus shown in Figures 6 and 8 as described hereinbelow.

Turning to Figure 5, the drive scroll member end plate 82-2 defines a radially extending lubricant passage 200-2. The lubricant passage 200-2 is provided with a lubricant passage outlet 202-2 for flow communication from the lubricant passage 200-2 to the first chamber 204-2 which is defined by the action of the outer tip portions 206-2 and 208-2 of the first and second scroll wraps 80-2 and 100-2 respectively. As the drive scroll member 76-2 and the idler scroll member 78-2 rotate on parallel but non-aligned axes, the first chamber alternately opens and closes, acting as a suction inlet when the scroll apparatus 20-2 is functioning as a compression device. An annular seal 210-2 is provided in a groove 212-2 in a face of the central portion 32-2. Preferably, the seal 210-2 is forced into contact with the drive scroll member end

plate 82-2 by an annular spring 214-2. The annular spring 214-2 cooperates with the annular seal 210-2 to prevent flow of lubricant radially outward from a collection chamber 217-2 defined by the seal 210-2, the drive scroll member end plate 82-2, and the central portion 32-2. Lubricant collected in this collection chamber 217-2 flows to a lubricant passage inlet 216-2 defined in the drive scroll member end plate and thence into the lubricant passage 200-2 which provides flow communication from the inlet 216-2 to the lubricant passage outlet 202-2.

In operation, during rotation of the scroll members 76-2 and 78-2, lubricant flows into the oil passage 182-2 to lubricate the upper main bearing 38-2. Typically this lubricant is at discharge pressure, although it may be throttled to a lower pressure. After having lubricated the upper main bearing 38-2, the lubricant is typically discharged at or slightly above suction pressure and is collected in the upper collection chamber 217-2. The lubricant then flows into the lubricant passage inlet 216-2 through the lubricant passage 200-2 and into the first chamber 204-2 via the outlet 202-2.

Turning now to Figure 6, a second alternative embodiment of the scroll apparatus 20-3 comprises a first, or idler scroll member 78-3 and a second, or drive, scroll member 76-3. A lubricant passage 200-3 is drilled from the outer peripheral end of the scroll end plate 82-3 in the second scroll member 76-3 radially inward to joint a lubricant passage outlet 202-3. A lubricant pickup tube 220-3 is provided. The pickup tube 220-3 extends from the second scroll member end plate 82-3 into a sump 222-3 defined by the lower shell portion 26-3 of the hermetic shell. Lubricant from the bearings of the scroll apparatus

20-3 as well as that which is precipitated from the incoming suction pressure fluids by the centrifugal action resulting from the centrifugal flow field generated in the incoming suction pressure fluids by the rotation of the scroll members 76-3 and 78-3 during operation of the scroll apparatus 20-3 is collected in the sump 222-3. The pickup tube 220 includes at its lowest end an inlet aperture 232-3 which is oriented so that lubricant collected in the sump 222-3 is forced into the aperture 232-3 during rotation of the pickup tube 220-3. The pickup tube 220-3 is formed with the requisite bends to place the lubricant inlet aperture 232-3 substantially within the radius of the lubricant passage outlet 202-3, as defined by the axis upon which the second scroll member 76-3 rotates. This permits the lubricant pickup tube 220-3 to effect a centrifugal pumping action which forces lubricant into the tube 220-3, through the lubricant passage 200-3 and out of the lubricant outlet 202-3 into the first chamber 204-3.

Examples of a lubricant inlet aperture end portion 234-3 in which the lubricant inlet aperture 232-2 is disposed are shown in Figures 6A, 6B and 6C. In these figures, the direction of travel is indicated by the arrow adjacent the inlet aperture 232-3. In Figure 6A, the inlet portion 234-3A is provided with a perpendicular end in which an aperture 232-3A is disposed. In Figure 6B, the inlet portion 234-3B is provided with an angled tip in which the lubricant inlet aperture 232-3B is disposed. In Figure 6C, the inlet aperture 232-3C is enlarged relative to the inlet portion 234-3C so that a relatively larger area is swept by the pickup tube 220-3C thereby ensuring an adequate flow of lubricant. In each example, the lubricant inlet aperture 232-3 is directed into the

lubricant so that lubricant is forced into the lubricant pickup tube. Those skilled in the relevant art will recognise that the inlet portion 234-3 may equally take an alternative form and that the examples shown may be applied equally to the lubricant pickup tubes 220 of the other embodiments of the scroll apparatus described herein.

The pressure head on the lubricant which is developed by the relative velocity of the pickup tube 220-2 to the lubricant and any centrifugal pumping action due to the relative positioning of the outlet 202-3 and the inlet portion 234-3 will vary considerably according to the scroll apparatus in which it is employed.

In operation of the scroll apparatus 20-3 the pickup tubes 220-3 are rotated about the axis of the second scroll member 76-3 in the sump 222-3, forcing fluid into the inlet apertures 232-3 by virtue of the pressure differential generated by the relative velocity of the pickup tube to the lubricant in the sump 222-3. The lubricant thus picked-up is forced through the pickup tube 220-3 into the lubricant passage 200-3 and out of the lubricant outlet 202-3 into the first chamber 204-3.

In Figure 7, a lubricant passage 200-4 is provided in the end plate 102-4 of the idler scroll member 78-4. A lubricant passage outlet 202-4 is provided for flow communication from the lubricant passage 200-4 to the first compression chamber 204-4. As with the embodiment shown in Figure 3, the lubricant passage 200 is drilled in the end plate and sealed at the outer end thereof by a plug 218-4. A lubricant passage inlet 216-4 is defined in the idler scroll member end plate at the inner radial end of the lubricant passage 200-4 for accepting oil from a

collection chamber 217-4 defined by the thrust bearing 176-4, the lower bearing housing 112-4 and the idler scroll member 78-4. In operation, lubricant is provided to the lower bearing 110-4 from the reservoir 180-4 through the assembly comprised of the bore 184 in frame portion 28-4, the lubricant feed tube 186-4 and the passage 188-4. After lubricating the lower bearing 110-4, the lubricant flows into the above described collection chamber 217-4 and then into the lubricant passage 200-4 by way of the lubricant passage inlet 216-4, whereupon it flows into the first chamber 204-4 via the lubricant passage outlet 202-4.

A third alternative embodiment of the scroll apparatus 20-5 is shown in Figure 8. In this embodiment, a lubricant passage 200-5 is provided through the end plate 102-5 of the second, or idler, scroll member 78-5. A lubricant pickup tube 220-5 is provided for flow communication from the sump 222-5 in the lower shell portion 26-5 to the first chamber 204-5 via the lubricant passage 200-5 and outlet 202-5. As with the lubricant pickup tubes described with reference to Figures 6A, 6B, 6C, an inlet aperture 232-5 is provided. In operation, the pickup tube 220-5 is rotated with the second scroll member 78-5 generating a pressure head and centrifugal pumping action which causes lubricant to be forced through the intake aperture 232-5 through the lubricant pickup tube 220-5 and into the lubricant passage 200-5 and out into the first chamber 204-5.

Those skilled in the art will recognise that various combinations of the embodiments shown in Figures 6 and 8 with the scroll wrap lubricating means shown in Figures 5 and 7 are readily possible, and that these alternative embodiments may be combined with various drive means for operating the scroll members

76, 78.

An example of one possible combination is shown in Figure 9 as a fourth alternative embodiment. In this example of the scroll apparatus 20-6, the second, or idler scroll member 76-6 is provided with a lubricant passage 200-6 which is in flow communication with the first chamber 204-6 through a lubricant outlet 202-6 of the lubricant passage 200-6. The pickup tube means for picking-up lubricant for delivery to the lubricant passage 200-6 comprises a lubricant pickup tube 220-6 and a lubricant transfer tube 280-6. The lubricant pickup tube 220-6 extends from the compression plate 150-6 into the sump 222-6. A lubricant transfer passage 270-6 is provided in the compression plate 150-6 for flow communication between the lubricant pickup tube and the lubricant transfer tube 280-6. The lubricant pickup tube 220-6, the compression plate transfer passage 270-6 and the lubricant transfer tube 280-6 taken together provide a lubricant flow path between the sump and the lubricant passage. The scroll apparatus 20-6 in this exemplary embodiment is also provided with features shown in Figure 5. An annular seal 210-6 is disposed in the annular groove 212-6 and secured therein by the spring 214-6 to comprise the collection chamber 217-6 for collecting oil from the upper main bearing 38-6. The lubricant in the collection chamber is communicated to the lubricant passage 200-6 through an inlet 216-6 defined in the second scroll member 76-6. In operation, this alternative embodiment of the scroll apparatus 20-6 provides lubricant to the first chamber 204-6 from both the sump 222-6, through the pickup tube 220-6, and the collection chamber, through the inlet 216-6.

A fifth alternative embodiment is shown in Figure

12. In this embodiment, the means for rotatably supporting the idler scroll member 78-7 are interchanged as compared with the previous embodiment. The lower bearing housing 112-7 and the idler scroll member shaft 104-7 are functionally reversed in that the lower bearing housing is smaller in diameter than the idler scroll member shaft 104-7, which is cylindrical. As with the other embodiments, a bearing 110-7 is provided to journal rotation of the idler scroll member shaft 104-7. No detailed description is believed necessary of the particulars of such a design, as they are believed generally known to those skilled in the art. However, the idler, or second, scroll member shaft 104-7 is provided with lubricant passages 200-7 for flow connection with pickup tubes 220-7 extending from the end of the shaft 104-7 adjacent the sump 222-5. This embodiment is operationally equivalent to that described in Figure 8, but provides for a more compact embodiment useful in smaller capacity scroll apparatus.

Returning again to Figures 1 and 3 for reference, the operation of the exemplary scroll apparatus 20 can be described. In operation, the motor 40 of the compressor assembly 20 is connected to an appropriate electrical supply (not shown) and actuated to cause rotation of the rotor 44. The rotor 44 in turn rotates the drive shaft 84, driving the driven, or first scroll member end plate 82. The extension members 120 and the compression member 150 cause rotation of the biasing element spring 170 and thereby the idler or second scroll member 78. Because the axes of the first scroll member 76 and the second scroll member 78 are not aligned, a relative orbital motion is set up between the driven scroll wrap 80 and the idler scroll wrap 100 causing a plurality of

chambers to be formed. The first chamber 204 as defined by the outer scroll portions 206 and 208 is alternately open to the suction space and closed therefrom during rotation of the scroll members. The chambers thus formed are of decreasing volume toward the radially inward ends of the respective scroll wraps 80 and 100, such that fluid drawn into the first chamber is compressed as it is moved toward the radially inward ends of the respective scroll wraps 80 and 100.

The compressed fluid is then discharged from the scroll wraps 80 and 100 through the discharge aperture 88 into the discharge gallery 86 and thereafter into the discharge pressure portion of the hermetic shell 22 defined in the upper shell portion 24. Lubrication of the bearings 38 and 110, as well as the other components of the compressor assembly 20, is accomplished by the action of pressure upon the fluid contained in the reservoir 180. Lubricant is forced through the bearing lubrication aperture 182 to lubricant the upper main bearing 38, and is discharged into the suction pressure space thereafter. Lubricant for the lower main bearing 110 passes through the passage 184, the lubricant feed tube 186 and the passage 188 with lubricant entering the collection chamber 217 (as described above) thereafter. Lubricant in the collection chamber flows into the second scroll lubricant passage 200 through the lubricant passage inlet 216. Lubricant separated from inlet suction fluid flows into the sump 222 and accumulates therein with that discharged from the upper main bearing 38. Lubricant accumulating within the sump 222 is forced into the lubricant pickup tube inlet aperture 232 by the rotation of the second scroll member 78 and thereafter is pumped through the

pickup tube 220 into the lubricant passage 200 and into the first chamber 204.

Those skilled in the art will appreciate the fact that the pickup tubes 220 will maintain the level of the sump 222 at a desired level, preventing an undesirable accumulation of fluid, whether the fluid is lubricant alone or condensed from the gases to be compressed or other unpumped fluid. The various lubricant passages 200 provide the desired effect of maintaining adequate lubrication of the scroll wraps 80 and 100 without undue consumption of power in the pumping of lubricant. The lubricant within the scroll wraps provides the additional benefit of improving the sealing of the compression chambers as well. Furthermore, the above-described lubrication of the scroll wraps via the lubricant passages is readily implemented in the scroll apparatus 20 without substantial modification thereto. The provision of constant lubrication is desirable and prevents unnecessary wear in the scroll wraps, at the same time assuring adequate lubrication of all moving components thereby reducing unnecessary wear and undue maintenance in the compressor assembly 20. It will be appreciated, therefore that the compressor assembly 20 provides improved reliability and a longer operating life as compared to the previous scroll apparatus.

In the embodiments a co-rotational scroll apparatus for use as a compressor comprises two scroll members each having a scroll wrap thereon for interleaving engagement with the other respective scroll wrap and adapted for concurrent rotation. The scroll members operate in a container or shell which is provided with an inlet for fluid which is oriented so that the axes of the scroll members are generally vertical. One or both of the scroll members is

provided with passages which communicate through the scroll member for discharging lubricant between the scroll member end plate through outlets, or openings, adjacent the outer end of the scroll wraps adjacent the point where the scroll wraps form the first chamber thereby providing lubricant to the entire scroll wrap length. The discharge outlets can be disposed in the scroll member end plate at any location adjacent the outer ends of the scroll wraps which will permit lubricant flow into the first chamber as it is formed.

Lubricant is provided to the passages by pickup tubes generally extending from the, or each, scroll member having the passages into the sump formed in the bottom portion of the container. The pickup tubes rotate with the scroll member end plates and have end openings oriented in the direction of travel. Rotation of the pickup tubes generates a pressure differential due to the velocity of the pickup tubes within the lubricant sump whereby lubricant passes into the tubes and is forced into the passages. An additional force contributing to the lubricant pickup is centrifugal force. This force is a result of disposing the pickup tubes radially inward of the discharge outlet of the passage.

Additional lubricant from the respective scroll member bearings may be delivered to the scroll member lubricant passages through inlet openings disposed adjacent the bearings. A seal is provided between the scroll member and the selected bearing to form a collection chamber for lubricant discharged from the bearing. The inlet openings are located radially inwardly of the lubricant passage outlets such that centrifugal force developed by the rotation of the scroll member moves the collected lubricant from the

collection chamber to the outlet.

5 It will be appreciated that the co-rotational scroll apparatus of the embodiments will be efficient in operation and suitable for use in closed circuit systems such as refrigeration systems. Furthermore, a co-rotational scroll apparatus in which controlled, effective and adequate flow of lubricant therethrough is provided, being at the same time simple in construction and suitable for inexpensive mass
10 production.

Modifications to the embodiments will be apparent to those skilled in the art within the scope of the claims that follow hereinbelow.

CLAIMS:

1. A scroll apparatus comprising:

a first scroll member having an end plate and a scroll wrap disposed on said end plate;

5 a second scroll member having an end plate and a scroll wrap disposed thereon, said scroll wraps being cooperably arranged for forming, in use of the apparatus, an alternately open and closed first chamber therebetween, said second scroll member end plate defining a lubricant passage having an outlet in
10 flow communication with said first chamber;

tube means in flow communication with said lubricant passage and arranged to pick-up lubricant, in said use of the apparatus, for delivery to said
15 lubricant passage; and

means for rotating said first and second scroll members.

2. A scroll apparatus as claimed in claim 1, further comprising means for biasing said scroll members
20 towards one another.

3. A scroll apparatus as claimed in claim 2, wherein said means for biasing comprises a plate member connected to said first scroll member, said plate member having a through-aperture which is penetrated
25 by said tube means.

4. A scroll apparatus as claimed in claim 1, 2 or 3, wherein said tube means comprises a lubricant pickup tube affixed to said second scroll member.

5. A scroll apparatus as claimed in any one of the preceding claims, further comprising a sump and baffle
30 means, said baffle means being arranged for reducing



the rotational velocity of lubricant in said sump.

5 6. A scroll apparatus as claimed in any one of the preceding claims, further comprising means for rotatably supporting said second scroll member, means for lubricating said means for rotatably supporting the second scroll member and means for delivering lubricant from said means for rotatably supporting said second scroll member to said lubricant passage.

10 7. A scroll apparatus as claimed in any one of the preceding claims, wherein said first scroll member defines a lubricant passage having an outlet in flow communication with said first chamber.

15 8. A scroll apparatus as claimed in claim 7, further comprising a lubricant pickup tube affixed to said first scroll member which pickup tube is in flow communication with said lubricant passage of said first scroll member.

20 9. A scroll apparatus as claimed in claim 7 or 8, further comprising means for rotatably supporting said first scroll member, means for lubricating said means for rotatably supporting said first scroll member and means for delivering lubricant from said means for rotatably supporting said first member to said lubricant passage of the first scroll member.

25 10. A scroll apparatus comprising:
a shell defining a suction pressure portion and a sump;
a first scroll member disposed in said suction pressure portion, said first scroll member having an
30 end plate having a shaft and an oppositely directed



scroll wrap disposed thereon;

5 a second scroll member disposed in said suction pressure portion, said second scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being in interleaving engagement for cooperably forming, in use of the apparatus, an alternately open and closed first chamber therebetween, said second scroll member end plate defining a lubricant passage having an outlet disposed adjacent an outer end of the scroll wrap of said second scroll member for flow communication with said first chamber;

10 a lubricant pickup tube affixed to said second scroll member for picking up lubricant from said sump and delivering it to said lubricant passage;

15 bearing means for rotatably supporting said first scroll member and said second scroll member; and

means for concurrently rotating said first and second scroll members.

20 11. A scroll apparatus as claimed in claim 10, wherein said lubricant pickup tube comprises an inlet orifice disposed in said sump.

25 12. A scroll apparatus as claimed in claim 10 or 11, further comprising baffle means for reducing the rotational velocity of lubricant in said sump.

13. A scroll apparatus as claimed in claim 10, 11 or 12, wherein said lubricant pickup tube is L shaped.

30 14. A scroll apparatus as claimed in any one of claims 10 to 13, further comprising means for lubricating said second scroll member bearing means and means for delivering lubricant from said second



scroll member bearing means to said second scroll member lubricant passage.

5 15. A scroll apparatus as claimed in claim 14, wherein said means for delivering lubricant to said second scroll member lubricant passage comprises a lubricant collection chamber disposed adjacent said shaft of the second scroll member, said collection chamber communicating with an inlet to said lubricant passage defined in said second scroll member.

10 16. A scroll apparatus as claimed in any one of claims 10 to 15, wherein said first scroll member defines a lubricant passage having an outlet in flow communication with said first chamber.

15 17. A scroll apparatus as claimed in claim 16, further comprising a lubricant pickup tube affixed to said first scroll member in flow communication with said lubricant passage of said first scroll member.

20 18. A scroll apparatus as claimed in claim 16 or 17, further comprising means for lubricating said first scroll member bearing means and means for delivering lubricant from said first scroll member bearing means to said lubricant passage of the first scroll member.

25 19. A scroll apparatus as claimed in claim 19, wherein said means for delivering lubricant to said first scroll member lubricant passage comprises a lubricant collection chamber disposed adjacent said shaft of the first scroll member which collection chamber communicates with an inlet to said lubricant passage defined in said first scroll member.



* C L H S *

20. A scroll compressor apparatus comprising:

a hermetic shell defining a suction pressure portion, a discharge pressure portion and a sump in said suction pressure portion;

5 a first scroll member disposed in said suction pressure portion, said first scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said first scroll member comprising a lubricant passage having an outlet
10 defined in said end plate;

a second scroll member disposed in said suction pressure portion, said second scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being
15 in interleaving engagement for cooperably forming, in use of the apparatus, an alternately open and closed first chamber, said chamber being in flow communication with said outlet;

pickup tube means cooperating with said lubricant passage to define a flow path between said sump and
20 said outlet;

respective bearing means for rotatably supporting said first and second scroll members;

means for lubricating said first and second scroll member bearing means; and
25

a motor driveably connected to said shaft of the first scroll member for rotating said first scroll member; and

means for concurrently rotating said second scroll member with said first scroll member.
30

21. A scroll compressor as claimed in claim 20, further comprising a compression plate connected to said first scroll member.



22. A scroll compressor as claimed in claim 21, wherein said pickup tube means comprises a lubricant pickup tube secured to said compression plate.

5 23. A scroll compressor as claimed in claim 22, wherein said compression plate comprises a lubricant transfer passage in flow communication with said lubricant pickup tube.

10 24. A scroll compressor as claimed in claim 23, wherein said pickup tube means further comprises a lubricant transfer tube extending between said first scroll member end plate and said compression plate for flow communication between said lubricant transfer passage and said lubricant passage of the first scroll member.

15 25. A scroll compressor as claimed in any one of claims 20 to 24, further comprising means for delivering lubricant from said first scroll member bearing means to said lubricant passage.

20 26. A scroll compressor as claimed in claim 25, wherein said hermetic shell comprises a central shell portion for separating said suction pressure portion and said discharge pressure portion.

25 27. A scroll compressor as claimed in claim 26, wherein said means for delivering comprises an annular seal disposed between said central shell portion and said first scroll member end plate for defining a collection chamber for collecting lubricant from said first scroll member bearing means.

28. A scroll compressor as claimed in claim 27,



wherein said first scroll member further defines an inlet to said lubricant passage, said inlet communicating between said lubricant passage and said collection chamber.

5 29. A scroll compressor as claimed in any one of claims 20 to 28, further comprising baffle means disposed in said suction pressure portion for reducing the rotational velocity of lubricant in said sump.

10 30. A refrigeration system for circulating refrigerant in closed loop connection, the system comprising:

a condenser for condensing refrigerant to liquid form;

15 an expansion device for receiving liquid refrigerant from said condenser and expanding said refrigerant;

an evaporator for receiving refrigerant from said expansion device and evaporating the refrigerant to vapour form; and

20 a compressor for receiving refrigerant from the evaporator and compressing and sending the refrigerant to the condenser, said compressor comprising:

25 a hermetic shell defining a suction pressure portion, a discharge pressure portion and a sump in said suction pressure portion;

30 a first scroll member disposed in said suction pressure portion, said first scroll member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said first scroll member defining a lubricant passage;

a second scroll member disposed in said suction pressure portion, said second scroll



* C L M S *

member having an end plate having a shaft and an oppositely directed scroll wrap disposed thereon, said scroll wraps being in interleaving engagement for forming, in use of the compressor, an alternately open and closed first chamber therebetween, said chamber being in flow communication with said lubricant passage defined in said first scroll member;

pickup tube means in flow communication with said lubricant passage and said sump;

bearing means for rotatably supporting said first scroll member;

bearing means for rotatably supporting said second scroll member;

means for lubricating said second scroll member bearing means; and

a motor driveably connected to said first scroll member shaft for rotating said second scroll member concurrently with said first scroll member.

31. A refrigeration system as claimed in claim 30, further comprising a compression plate connected to said first scroll member.

32. A refrigeration system as claimed in claim 31, wherein said pickup tube means comprises a lubricant pickup tube which is secured to said compression plate.

33. A refrigeration system as claimed in claim 32, wherein said compression plate comprises a lubricant transfer passage in flow communication with said pickup tube.



34. A refrigeration system as claimed in claim 33,
wherein said pickup tube means further comprises a
lubricant transfer tube extending between said first
scroll member end plate and said compression plate for
5 flow communication between said lubricant transfer
passage and said lubricant passage of the first scroll
member.

35. A refrigeration system as claimed in any one of
claims 30 to 34, wherein said hermetic shell comprises
10 a central shell portion for separating said suction
pressure portion and said discharge pressure portion.

36. A refrigeration system as claimed in claim 35,
further comprising means for lubricating said first
scroll member bearing means.

37. A refrigeration system as claimed in claim 36,
wherein said means for delivering comprises an annular
seal disposed between said central shell portion and
said first scroll member end plate for defining a
collection chamber for collecting lubricant from said
15 means for lubricating said first scroll member bearing
means.
20

38. A refrigeration system as claimed in claim 37,



wherein said first scroll member comprises an inlet communicating between said lubricant passage and said collection chamber.

39. A co-rotational scroll-type fluid-transfer apparatus wherein provision is made for lubricant flow through the length of the scroll wraps by virtue of there being provided tube means which in operation of the apparatus picks-up lubricant for delivery to a lubricant outlet arranged for introducing said lubricant into the region where the scroll wraps in said operation cooperate to define an initial fluid-transfer chamber.

40. A co-rotational scroll-type fluid-transfer apparatus substantially as herein described with reference to Figures 1 and 3, 4, 6, 8, 9 or 12 of the accompanying drawings.

